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ORIGINAL ARTICLES.

I.—On some British Pillow-lavas and the Rocks associated with them.

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(By permission of the Director of H.M. Geological Survey.)

(*Concluded from the May Number, p. 209.*)

IF we take a rapid glance over the volcanic history of the British Isles we find that eruptions having the spilitic facies occurred repeatedly, over a wide area and on a large scale.

Pre-Cambrian. Among the Dalradian Schists of the West of Scotland pillow-lavas were first recognized by Peach (30). They are well shown on the shore at Tayvallich on the Sound of Jura, and extend thence through Argyllshire past Loch Awe. Representatives of this series are met with at Ardwell in Banffshire. The accompanying sediments are the quartzites, black shales, and limestones of the Central Highlands. Albite-diabases represent the intrusive phase, and there are also keratophyres and soda-granites. The age of this series is uncertain, but perhaps it is pre-Cambrian.

In Anglesey and the Lleyn District of Carnarvonshire pillow-lavas with variolitic structure have been described by Raisin (31) and Greenly (32). With them there are diabases and cherts, but no acid rocks are known. These also are perhaps pre-Cambrian.

Cambrian (?). Radiolarian cherts and pillow-lavas occur in a narrow strip along the southern border of the Scottish Highlands extending from Stonehaven into Arran. Diabases accompany them, but no acid rocks, though serpentine and gabbro are found in lenticles, the relations of which to the lavas and cherts are unknown. The sediments are black shales, grits, and limestones, and Dr. Peach thinks it likely that they will ultimately prove to be Upper Cambrian (33).

Ordovician. To this series belong the Arenig volcanics of the South of Scotland and the Arenig or Llandilo pillow-lavas of South Cornwall. In both places there are diabases, keratophyres, and soda-felsites or soda-granites.

About the same time there were eruptions in South Wales emitting keratophyres, soda-felsite, variolite, and diabase, and Thomas (34) has found a remarkable suite of rocks on Skomer Island that presents many resemblances to the Arenig igneous rocks of South Scotland, though only one or two flows of pillow-lava have been detected in it. They include keratophyre, soda-trachyte and soda-felsite, diabase (not

albitized), and basic rocks rich in albite, called skomerite and marloesite. In Ireland Reynolds and Gardiner have found typical pillow-lavas, cherts, and diabases of Arenig age.

In Upper Silurian times no spilitic eruptions have yet been recorded in Britain.

Devonian. The great development of spilite and schalstein in Cornwall and Devon perhaps began in Middle Devonian times, and attained its maximum in Upper Devonian or Lower Carboniferous times. They are accompanied by albite-diabase, minverite, quartz-diabase, pierite, and quartz-keratophyre.

The subjoined table shows the facies developed from the magma in each epoch at different localities:—

	Soda-granite.	Soda-felsite and Quartz-keratophyre.	Keratophyre.	Spilite.	Diabase.	Quartz-diabase.	Minverite.	Pierite.
Argyllshire . . .	1	—	1	1	1	1	?	—
Anglesey and Lleyn	—	—	—	1	1	—	—	—
Stonehaven . .	—	—	—	1	1	—	—	—
Southern Scotland	—	1	1	1	1	—	—	—
South Cornwall .	1	—	1	1	1	—	—	—
South Wales . .	—	1	1	1	1	—	—	—
Devon and Cornwall	—	1	1	1	1	1	1	1

Harker (35), Prior (36), and Becke (37) have of recent years established the existence of two great suites of eruptive rocks, the Atlantic and the Pacific, and their conclusions have been accepted by Suess (38). In the British Isles we have many examples of these in past time. The Tertiary eruptions of Scotland are of Atlantic facies; the Carboniferous of the Scottish Lowlands are Atlantic also, but the Old Red are Pacific, while the Ordovician are of the spilitic type.

In Devon and Cornwall the Ordovician eruptions were spilitic, the Devono-Carboniferous were spilitic, but the Permian were Atlantic, and characterized by trachytes rich in potash. From this we see that the same region may in successive geological epochs be the focus of eruptions of entirely distinct suites of volcanic rocks.

The Pacific volcanic rocks are generated by epochs of active folding, the Atlantic by vertical movements attended by faulting. The spilitic group is characteristic of off-shore subsidences. They are the characteristic volcanic rocks of districts that have been undergoing long-continued subsidence (39). Hence they are not found on the land at the present day, and, in the past, their commonest associates are fine black shales, limestones, and radiolarian cherts.

It is interesting to recall that in Lower Ordovician times, while the spilites and keratophyres of Southern Scotland and the South of

Cornwall were being poured out, eruptive centres in Cumberland were emitting hypersthene andesites and other rocks of Pacific type: on the other hand, in the Lower Carboniferous period, spilites and quartz-keratophyres were the characteristic lavas of Devonshire and Cornwall, while trachytes, phonolites, olivine-basalts, teschenites, and nepheline-basalts of Atlantic facies were the dominant igneous rocks of East Lothian in Scotland.

In 1899 Teall (25) remarked that "it is interesting to note that at Ballantrae in Cornwall and in Mont Genèvre diabasic lavas with pillow-structure occur in the immediate neighbourhood of gabbro and serpentine, and that in all three localities some difficulty is experienced in determining the precise relations of these rocks". The constant association of diabase (spilite), serpentine, and gabbro in the northern Alps with radiolarian cherts has led Steinmann (37) to regard these 'ophiolitic eruptives' as the typical volcanic rocks of abysmal depressions. Suess has accepted and extended this hypothesis, considering the 'green rocks' to be injections into folded ranges associated with dislocations, but not invariably with deep-sea conditions (38). The 'ophiolitic eruptives' of Steinmann are not coextensive with the spilitic suite of igneous rocks as here defined, and still less so are the 'green rocks' of Suess. In several parts of Britain the association of gabbro and serpentine with spilitic lavas is difficult to explain as a mere accident, but we have not been able to establish definitely, in those parts of Cornwall or of Scotland with which we are personally familiar, that the one series is the plutonic representative of the other. For the present we prefer to regard this as an open question, hoping to return to its consideration at some future time.

The Adinoles.

That type of alteration by which shales and slates are converted into adinoles has been produced by basic intrusive rocks of more than one class. In the Lothians, for example, it occurs at the margins of some teschenite sills, and quartz-diabases sometimes also induce it. But there can be no doubt that the albite-diabases that belong to the spilite suite of igneous rocks are more efficient in changing shales to adinoles than all the other kinds of diabase. In Cornwall and Devon adinoles occur with great frequency both in the Devonian and Culm, and the adinole of Dinas Head is especially well known through the descriptions of Fox and Teall and the analyses of Hort Player (40). We may further remind our readers that an extensive literature has been written about the similar rocks of the Rhine district, which also occur in contact with the late Devonian and early Carboniferous intrusive sills that belong to the spilitic volcanic series.

The adinoles in their highest development are nearly pure albite rocks. No shales have a similar composition, for none are so rich in alkalies, yet the transformation of a shale into an adinole often takes place within a few inches. Hence there is no escape from the conclusion that there has been an infusion of new substances, principally soda, into the sediment, and this has been generally

admitted by petrographers for many years. For a summary of the literature on this subject we may refer to Roth (41).

In its microscopic structures the adinole is no less evidently a recrystallized sediment. The lamination, cleavage, and bedding are soon lost, and a cryptocrystalline or finely crystalline rock is produced that has the closest resemblance to a chert. In North Cornwall and Devon cherts and adinoles constantly occur together in the same quarry. Very often they can hardly be distinguished except for the fact that the felspar of the adinole has a lower refractive index than balsam, while the quartz has the same or slightly higher; moreover, the adinoles are fusible while the cherts are not. By further recrystallization the adinoles become a mosaic of albite grains that have very closely the same mode of aggregation as the silicified shales found associated with some mineral veins (such, for example, as the flinty Ordovician shales of Parys Mountain in Anglesey). Now the cherts are admittedly rocks that have been recrystallized from colloid organic silica through the agency of aqueous solutions, and an allied mode of origin seems probable for the adinoles. In the latter we may often note the meshwork of veins filled with albite slightly more crystalline than the matrix, through which the solutions were introduced. The adinoles consist of quartz, albite, and chlorite (with rutile and iron oxides), and these are also the minerals that most characterize the post-volcanic or pneumatolytic stage of crystallization in the albite-diabases.

That adinoles should accompany albite-diabases is exactly what might be expected, for the pneumatolytic or post-volcanic vapours by which the intrusive rocks were albitized provide also the necessary constituents for the albitization of the sediments. In this respect the adinoles are not unlike the tourmalinized killas that occurs at the margins of the Cornish granites, where the same vapours as attacked the sediments also attacked the granite itself, converting it into schorl rock. The remarkable chemical changes that take place in the transformation of shale into adinole are the clearest evidence that could be adduced to show that vapours or solutions rich in soda were emitted by the igneous rocks during the later stages of their crystallization.

The Cherts.

That pillow-lavas are usually accompanied by radiolarian cherts is now a well-established fact. Attention has been directed to this paragenesis by Teall (42), and in all parts of Britain in several geological epochs it has since been proved to hold good.

As already stated, the spilitic rocks occur typically as submarine lavas in regions remote from shore-lines where the water is of considerable depth. These also are in a high degree the conditions that seem favourable for the deposition of siliceous organic deposits. The association then is a natural one, just as radiolarian cherts occur with fine graphitic shales and limestones.

But this is not the whole truth. How often do we find the cherts nestling in the hollows between the pillows even where limestones are few or absent, and where the sediments are of rather coarse grain and belong to shallow-water facies. In Cornwall pillow-lavas are

found in the Middle and Upper Devonian; the attendant sediments are shales and grits, but Ussher (43) found that between the pillows of the lava on the shore at Saltash a few thin beds of chert occur, and in microscopic section they appear to be of radiolarian origin. No cherts are found in the Devonian rocks at lower levels, but as soon as the spilites are met with the cherts also make their appearance, and at first are only found on the upper surfaces of the flows. This fact awakens a strong suspicion that there must be some genetic connexion between these two kinds of rock. At higher horizons in Upper Devonian and Culm the pillow-lavas abound, and there are great masses of chert, but we cannot be sure that this is more than a coincidence, since in South Wales at the same time radiolarian cherts were being laid down in great sheets, and there are no pillow-lavas. Again, in the Lower Palæozoic rocks of Cornwall, as Fox (44) has shown, there are sometimes a few lenticles of chert among the black shales, but when the pillow-lavas flowed out on the sea-bottom in Arenig or Llandeilo time the cherts appeared at once in great quantity, and on Mullion Island they fill up the gaps between the sack-shaped masses of the igneous rock.

Recent researches on the plankton of the northern seas have proved that the modern organisms which form siliceous tests are dependent on the supply of silica in the water which they inhabit (45). At certain seasons a large increase in the amount of dissolved silica takes place, and this is followed almost immediately by rapid proliferation of the diatoms, etc., that inhabit the water. There seems no inherent reason why the 'law of the minimum', as it has been called, may not also have held good in Palæozoic times: if so, it explains the occurrence of organic cherts with pillow-lavas. The igneous rocks as they cooled down exhaled vapours or solutions of magmatic origin, rich in dissolved silicates of soda and other bases. These were the agencies which albitized and decomposed the lavas, and any excess must have escaped into the sea-water. In this way precisely those conditions were provided which are most favourable to the rapid multiplication of siliceous protozoa such as the radiolaria. As the spilitic rocks are generally found at some distance from the shore, in quiet waters where there was little sediment and current action was at a minimum, the radiolaria, though they may have been of slow growth, were not carried away. The dead shells fell to the bottom and rested on the surface of the lava, while there was comparatively little clastic or land-derived sediment to mingle with the siliceous organic deposit. Where there are no cherts with the spilites, as for example at Tayvallich, Argyllshire, we may infer either that the dissolved mineral substances were not in excess of those required to albitize the lava, or more probably, that the local action of currents bore away the minute siliceous shells and brought other sediment in their place.

Conclusions.

1. The pillow-lavas are members of a natural family of igneous rocks, the spilitic suite, that can be clearly distinguished from the Atlantic and Pacific suites.

2. This family comprises a great variety of types—picrites, diabase,

minverite, quartz-diabase, spilite, keratophyre, quartz-keratophyre, soda-felsite, and albite granite, ranging from ultra-basic to acid in composition.

3. Their essential characteristics are the abundance of soda-felspar, and the remarkable frequency with which they have been albitized.

4. The albitization is not characteristic of the whole suite, but is especially frequent in certain members of it, such as the spilites and diabases, while others like the quartz-diabases are less liable to this change. It is not due to weathering or shearing. Good evidence exists to prove that the albitization took place soon after the rocks had solidified, and consequently it may be grouped among the post-volcanic or juvenile changes of rock-masses.

5. The constant association of adinoles (albitized shales) with the albite-diabases, and of radiolarian cherts with pillow-lavas, finds a simple explanation on this hypothesis, and at the same time affords the strongest confirmation of it.

6. The composition of the pneumatolytic emanations cannot be exactly defined, but it is certain that they consisted of water with soda and silica in solution; probably also carbonic acid was abundant, and many other substances may have been present.

7. In the British Isles spilitic eruptions have appeared in great numbers in all the Palæozoic formations (with the exception of the Upper Silurian and the Permian), and in the Tayvallich Volcanic Series have an important development among the metamorphic schists of the Scottish Highlands.

8. Like the Atlantic and Pacific igneous suites they have an intimate connection with certain types of geographical conditions. They are essentially rocks of districts that have undergone a long-continued and gentle subsidence, with few or slight upward movements, and no important folding.

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II.—The Fundamental Problems of Petrogenesis, or the Origin of the Igneous Rocks.

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Introduction.

The question of the origin of igneous rocks, their diversity and genetic relationships, represents that fundamental problem of petrography which has been for many years the object of inquiry for petrologists as well as for geologists and chemists. Whilst the amount and scope of detailed observation were growing, the methods of experimental investigation improved, and as the eruptive rocks came to be studied from the point of view of physical chemistry, so the petrogenetical horizon became larger and wider. Thus, on the basis of numerous minute and detailed observations were built broad generalizations that gave rise to new problems.

If we try to determine by one word the successively predominant ideas in petrogenesis, we can say that, notwithstanding a certain diversity of opinions, from 1890 and for nearly fifteen years petrology was dominated by the idea of differentiation; from the middle of the last decennium the chief rôle belongs to the theory of eutectics; and during the last few years there has been slowly growing and advancing, as a necessary corollary and even as a dominant factor, the hypothesis of refusion and assimilation by fusion. A rational combination of the principles of assimilation, refusion, differentiation, and eutectics seems to be the best basis for a theory of the genesis and diversity of the igneous rocks, and probably the nearest approximation to the solution of the question may be my syntectic-liquational hypothesis[1] enlarged according to the progress of later years.

In the present paper[2] I propose to give my revised views on the genesis of the igneous rocks and the factors governing their diversity.

§ 1. *The Average Chemical Composition of the Earth's Crust and the Primordial Magma.*

Before entering into the problem of the genesis of the igneous rocks it is necessary to deal critically with a question of general interest, which has often been an object of inquiry for petrographers and chemists.

[1] F. Lœwinson-Lessing, "Études de pétrographie générale," p. 178: Trans. Soc. Nat. St. Pétersbourg, 1898. "Studien über die Eruptivgesteine," p. 187: Compt. rend. Congr. Géol. Inter., St. Pétersbourg.

[2] Originally written in Russian, August 27, 1910, and printed in the Annales de l'Institut Polytechnique de St. Pétersbourg, v, xiv, 1910, p. 111.

I mean the average chemical composition of the earth's solid crust as a whole, and especially that of the igneous rocks.

The problem of determining this average composition is very attractive. It is well known that the most important contributions to the solution of this problem have been given of late years by F. W. Clarke,[1] H. S. Washington, and Vogt. Without denying the value of their calculations and reasonings for elucidating the question of the relative abundance of the different elements in the solid crust, I must nevertheless state that the method used by these and other authors for calculating the average composition is in principle erroneous, and consequently the result is arbitrary. The arithmetical mean of hundreds or even thousands of analyses, when the relative quantities of the different types of rocks are not taken into consideration, has no serious value. Nevertheless the result is probably very near to the real average composition, as will be subsequently shown, because the figures given by Clarke[2] and several other authors represent approximately the mean of the composition of granite and gabbro (or basalt); and these two magmas are not only the most widely spread, but they seem to enter into the composition of the crust in nearly equal quantities. If we take, then, the mean only from the figures for granite and gabbro (basalt) we get a result which in essential features is nearly identical with the mean calculated from an arbitrary number of separate analyses of all known types of igneous rocks. But it is not this average magma, having nearly the composition of a syenite, which I consider the primordial terrestrial magma, and I do not think that all other rock-types such as granites, gabbros, etc., are derivates, produced by differentiation of one fundamental magma. On the contrary, as will be shown later, my hypothesis consists in admitting that there are two and only two fundamental magmas—the granitic and the gabbroidal (= basaltic), and that the eruptive rocks are derived from these two magmas by differentiation and assimilation.

TABLE I.

	I.			II.	III.	IV.		
	%			%	%	%		
SiO_2	59·57			58·24	60·91	59·57		
Al_2O_3	14·82	18·46		15·80	15·28	15·54	18·52	
Fe_2O_3	3·64			3·33	2·63	2·98		
FeO	4·12	13·05		3·87	3·46	3·67	12·70	
MgO	3·40			3·84	4·13	3·98		
CaO	5·53		19·27	5·22	4·88	5·05		19·45
Na_2O	3·20	6·22		3·91	3·45	3·68	6·75	
K_2O	3·02			3·16	2·98	3·07		
TiO_2	1·36			1·04	0·73	0·89		

[1] See, for instance, Clarke, "The Data of Geochemistry": Bull. U.S. Geol. Surv., No. 330, 1908.

[2] It must be noticed that in calculating the average composition of the whole crust Clarke (ibid.) takes for the sediments and the eruptives certain coefficients corresponding to their relative quantities in the solid crust. But why is the same method not applied to the calculation of the average for the eruptive rocks?

On Table I are given: (I) The average from basalt (after Daly [1]) and granite (after Holmquist [2]); (II) Washington's [3] and (III) Clarke's average for igneous rocks; (IV) the average between II and III. We can easily see that this last average agrees in its essential features with the composition of an earth magma, presumed to consist of equal parts of a granitic and a gabbroidal magma.

The same result is reached by taking the new data of Daly,[4] as can be seen from the figures on Table II. Washington's average and the mean from granite and gabbro are in the essential lines identical.

TABLE II.

	I.	II.	III.		IV.		V.	VI.	
	Granite after Daly.	Gabbro after Daly.	The mean of I and II.		The mean after Washington,[3] p. 114.		Basalt after Daly.	The mean of I and V.	
	%	%	%		%		%	%	
SiO_2	70·47	48·95	59·71		59·21		49·87	60·17	
TiO_2	0·39	0·98	0·68		1·06		1·38	0·89	
Al_2O_3	14·90	18·15	16·52	18·94	16·04	19·42	15·96	15·43	18·98
Fe_2O_3	1·63	3·21	2·42		3·38		5·47	3·55	
FeO	1·68	6·04	3·86		3·93		6·47	4·07	
MnO	0·13	0·13	0·13	15·05	—	13·13	0·32	0·23	13·55
MgO	0·98	7·62	4·40		3·90		6·27	3·62	
CaO	2·17	11·15	6·66		5·30		9·09	5·63	
Na_2O	3·31	2·59	2·95	5·45	3·97	7·18	3·16	3·24	6·06
K_2O	4·10	0·90	2·50		3·21		1·55	2·82	
P_2O_5	0·24	0·28	0·26				0·46	0·35	

Our first conclusion can be formulated as follows: The average composition of the crust, calculated by the method hitherto in use, corresponds to the composition the crust would have if it consisted of equal parts of granite and gabbro. What does this hypothetical fundamental magma represent? Examining the answers to this question given by different authors, we perceive that the current opinions are erroneous. Thus Daly, with whom I agree on many points, is wrong when he defines this magma as a dioritic one, because in calculating the average composition of diorite he has taken analyses, not of diorites only, but also of quartz-diorites (granodiorites) representing a different magmatic type from that of true diorites. In reality the average III on Table II corresponds almost exactly to the syenitic magma, as can be seen by the following calculation:—

[1] R. Daly, "Origin of the Augite-andesites": Jour. Geol., 1908, p. 409.
[2] Holmquist, "Studien über die Granite von Schweden": Bull. Geol. Inst. Upsala, vii, 1906.
[3] H. S. Washington, "Chemical Analyses of Igneous Rocks published from 1884 to 1900": U.S. Geol. Surv., Prof. Pap. No. 14, 1903.
[4] R. Daly, "Average Chemical Composition of Igneous Rock-types": Proc. Amer. Acad. Arts and Sciences, xlv, No. 7, p. 209, 1910.

TABLE III.

Molecular Ratios.

SiO_2	1·013		
Al_2O_3	0·165	0·180	
Fe_2O_3	0·015		
FeO	0·056		
MgO	0·112	0·275	
CaO	0·107		0·351
Na_2O	0·049	0·076	
K_2O	0·027		

3·5 $\bar{R}O$ 1·8 R_2O_3 10·1 SiO_2 or 1·95 $\bar{R}O$ R_2O_3 5·62 SiO_2.

$\alpha = 2·27$ $\beta = 52$ $\gamma = 1·90$.

$R_2O : RO = 1 : 3·6$.

Syenite: 1·8 $\bar{R}O$ R_2O_3 5·6 SiO_2.

$\alpha = 2·4$ $R_2O : RO = 1 : 2·2$.

Diorite: 1·5 $\bar{R}O$ R_2O_3 4 SiO_2.

$\alpha = 1·77$ $R_2O : RO = 1 : 4·3$.

Thus the average composition of the igneous rocks (probably of the entire outer part of the crust) corresponds nearly to the syenitic magma. Is this to be interpreted as meaning that the primordial magma is in reality a syenitic one? Such a conception exists, but we can oppose to it several geological data and petrogenetic considerations. If the syenitic magma were really the fundamental magma, from which were derived and are still derived all the other types of igneous rocks, we should expect that this magma would have a great development, that it would be represented by definite plutonic and volcanic regions, and that the eruption of granites, gabbros, and other 'derived' rocks would be preceded by an eruption of the fundamental magma. Observation does not confirm these suppositions. The syenitic intrusive bodies are generally of far smaller dimensions than the masses of granitic or gabbro-peridotitic-pyroxenitic formations; the syenites are often only a marginal facies (*Randfacies*) of these two formations. In regard to the well-known syenite of Plauen this connexion with the Meissen granite, and the subordinate position of the syenite, have been pointed out by Rosenbusch, and, as far as I can see, all syenites are only local facies of a granitic or a gabbroidal formation.

Were the syenitic formation the fundamental magma, and the other rocks derived from it, we should expect it to afford proofs of differentiation which we do not find, because the syenite is itself a derived magma, generated by one of the two above-mentioned formations, which show various processes of differentiation. The figures on Tables I and II demonstrate also that Rosenbusch was not right in considering that the monzonites and essexites represent the average composition of the terrestrial magma. Rosenbusch says,[1] speaking of the monzonites: ". . . dass sie zusammen mit den Essexiten ziemlich genau mit dem terrestrischen Gesammtmagma chemisch übereinstimmen," and further: ". . . Diese beiden Gesteinsfamilien [the monzonites and the essexites] stellen, um die

[1] H. Rosenbusch, *Mikroskopische Physiographie der massigen Gesteine*, 4th ed., pp. 142, 395, 1907.

wichtige Thatsache noch einmal zu betonen, die reinste ungespaltene Form des tellurischen Magmas dar. Darin liegt ihre hohe Bedeutung." He emphasizes also his opinion that the monzonitic magma is subject to large differentiation processes.

The following calculations show clearly that the monzonite and the essexite differ more from the average magma than the syenite:—

TABLE IV.

Monzonite (after the latest calculations of Daly)—

	%	Molecular Ratios.		
SiO_2	56·74	0·946		
Al_2O_3	16·97	0·166	0·185	
Fe_2O_3	3·11	0·019		
FeO	4·64	0·064		
MgO	4·31	0·108	0·282	
CaO	6·12	0·110		0·383
Na_2O	3·57	0·057	0·101	
K_2O	4·22	0·044		

3·8 $\bar{R}O$ 1·9 R_2O_3 9·5 SiO_2 or 2·07 $\bar{R}O$ R_2O_3 5·11 SiO_2.

$\alpha = 2·01$. $R_2O : RO = 1 : 2·8$.

Monzonites after Brögger[1]—

2·34 $\bar{R}O$ R_2O_3 5·05 SiO_2.

$\alpha = 1·91$. $\beta = 55$.

$R_2O : RO = 1 : 3·3$.

We can readily see that this magma is not more like the average one than is that of the syenite; the average magma is rather the mean between the monzonitic and the syenitic magmas (except as regards silica and the relation $R_2O : RO$). This magma in reality much resembles that of the syenite, and if we take my earlier formula for the gabbro-syenites (= monzonites), the difference between this magma and the average will appear even more evident.

The essexitic magma presents even less resemblance to the average terrestrial magma, as can be shown by the following calculations:—

TABLE V.

Essexite (after the latest calculation of Daly)—

	%	Molecular Ratios.		
SiO_2	50·02	0·834		
Al_2O_3	17·58	0·172	0·206	
Fe_2O_3	5·38	0·034		
FeO	6·50	0·090		
MgO	4·72	0·118	0·340	
CaO	7·40	0·132		0·439
Na_2O	4·68	0·075	0·099	
K_2O	2·23	0·024		

4·4 $\bar{R}O$ 2·1 R_2O_3 8·3 SiO_2 or 2·1 $\bar{R}O$ R_2O_3 4 SiO_2.

$\alpha = 1·58$. $R_2O : RO = 1 : 3·4$.

This magma corresponds to the vogesitic magma, and approximates to the syenito-dioritic one, but is very different from the terrestrial average.

[1] W. Brögger, *Die Eruptivgesteine des Kristianiagebiets*. II. Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo. 1895, p. 27.

Rosenbusch notes that the monzonitic and essexitic magmas are subject to large differentiation processes; this assertion, however, cannot be considered as correct, because the monzonites are one of the products of the largely differentiated gabbro-syenitic magma, but are not sensibly subject to differentiation.

Our conclusion is then the following:—Not one of the magmas, syenitic, monzonitic, or dioritic, can be considered as the primordial magma, from which were derived and are still derived all eruptive rocks. And not nearer to the truth are those who urge that the primordial magma is either a granitic or a basaltic one. Thus Mennell[1] criticizes the calculations of Clarke and others, and is quite right in objecting to their calculations, as they ought to have taken into consideration the relative quantities of the different types of igneous rocks. His own calculations for a part of Rhodesia lead him to support the view of a granitic magma; presuming that the granitic rocks equally predominate in all other countries, he is logically induced to consider the granitic magma as representing the primordial terrestrial magma. But the predominance of granitic rocks is certainly only apparent. For Sweden we have calculations which demonstrate that the granitic and the basic rocks are represented in nearly equal quantities; and such calculations would certainly give the same result for many other countries, where granites seem to predominate. And if in such parts of the globe as Finland the granitic rocks really or apparently predominate, there are other districts, as the Ural Mountains, where the predominance is certainly on the side of the different members of the basic magma, the gabbro-peridotitic-pyroxenitic magma.

What has been said of Mennell's hypothesis, is in full measure applicable to the basaltic magma, the antipodes of granite. Daly, who, as has been mentioned above, considers the terrestrial average to be a 'dioritic' magma, formerly expressed another point of view. In 1903[2] he regarded as the universal earth magma the basaltic (gabbroidal) magma, and pointed out that the other eruptive rocks are derivates, produced by abyssal assimilation and magmatic differentiation. This opinion was supported by the following facts:—The fissure-eruptions and the other cases of eruptions on a great scale are represented by the basalts; the basalts and andesites have a much wider distribution than other volcanic rocks; the last products of eruption (when the primordial magma is not further influenced by assimilation) are basaltic rocks (p. 110).

Dutton[3] has expressed similar ideas; he also considers the basalts as the 'primordial matter', and infers that the other types of volcanic rocks are the result produced by a refusion of sedimentary formations. But are the basalts and andesites really predominant amongst the volcanic formations? A definite and exact answer to this question

[1] F. P. Mennell, "The Average Composition of the Igneous Rocks," GEOL. MAG., 1904, p. 263; "The Constitution of the Igneous Rocks," ibid., May, 1909, p. 212.

[2] R. Daly, "The Geology of the Ascutney Mountains, Vermont": Bull. U.S. Geol. Surv., No. 209, 1903.

[3] Dutton, *The High Plateaux of Utah*, 1880, p. 125 (cited after Daly).

is at present difficult, indeed a satisfactory solution of the problem is probably not yet possible. We must remember that to the Silurian and Devonian diabases and melaphyres, we can oppose the Carboniferous and Permian porphyries, and that in the Archæan and Algonkian formations the porphyries, keratophyres, and porphyrides have an equal or even a larger development than the basic eruptions. The Tertiary fissure eruptions belong of course to the basaltic formations; but we know so little of the Jurassic and Cretaceous eruptions, and what would they tell us? We must not forget the trachytic, dacitic, and liparitic eruptions of the Tertiary, and we must also take into consideration that the basalts and andesites are not always the last products of eruption. If we also remember the before-mentioned quantitative relations between the granitic and the basic intrusives, we must confess that there are not sufficient data for considering the basaltic magma as the most widely developed one, and as representing the primordial and average terrestrial magma.

If we summarize all that has been said hitherto, we arrive at the conclusion that the average composition of the terrestrial magma does not correspond to a syenite, nor to a monzonite or essexite, a diorite, a granite, or a basalt (gabbro). Moreover, every hypothesis which regards the average terrestrial magma as corresponding to one definite eruptive rock and assumes only one primordial magma, from which all eruptive rocks are to be deduced, is erroneous; such a hypothesis could hardly be made to explain in a satisfactory manner all the peculiarities of distribution and the genetic relations of all eruptive rocks.

The mutual relations of the eruptive rocks may be explained most satisfactorily by the admission of two primordial magmas: a granitic and a gabbroidal (basaltic) one. In what way these two magmas have been generated and how they are distributed in the earth's crust, is a question that may remain open meanwhile. We take it as a fact that there must be admitted two independent primordial magmas, and only these two magmas, while all other eruptive rocks are derivates from them, originating by assimilation and differentiation. Such a hypothesis is based on the following facts and considerations.

1. Two primordial magmas of granitoidal and gabbroidal composition, entering into the composition of the solid crust nearly in equal quantities, give just the average composition of this crust which has been found hitherto by the calculations of different authors.

2. The different members of the granitic formation and the gabbro-pyroxenitic-peridotitic formation occur in much larger bodies and have a far greater development than the other eruptives. We know very large gabbro-noritic intrusive bodies which are often accompanied by a more or less varied series of differentiation products (pyroxenites, peridotites, anorthosites, and different vein- and dyke-rocks), but are quite independent and not connected with other intrusives: I can cite, for instance, the gabbro-formation of the Ural Mountains. We know also in several countries extensive and independent granitic bodies. On the other hand, the other rock-types form far less extensive bodies, have a smaller development, and occur generally as marginal or other facies of the granitic or gabbroidal formation. Thus the syenites are

closely connected with granites, forming a facies of these latter; the alkaline syenites are connected with alkaline granites; the diorites partly with the granites and partly with gabbros and norites. The quartz-diorites are of course largely developed, but they are connected petrographically and geologically with granites in such way that we might speak of a granito-granodioritic formation as we speak of a gabbro-pyroxenitic-peridotitic formation. The connexion between the pyroxenites, the peridotites, and the anorthosites with the gabbro formation has been already referred to. The gabbro-syenites (=monzonites) are equally derivates of the gabbro formation; such rocks as adamellites, shonkinites, missourites, etc., are evidently also facies of other regionally independent rocks. There remains one rock-type whose position was not clear to me, and which seemed to present a difficulty to my hypothesis of only two individual and independent magmas, the granitic and the gabbro-noritic—I mean the nepheline-syenites. But since Beljankin's[1] researches in one of the important regions, in the Ilmen Mountains of the Ural, have demonstrated the connexion of the nepheline-syenite (miaskite) formation with the granites, and Daly[2] has developed the view in a recently published paper that all the nepheline-syenites are derivates from granites, this last objection to my conception of only two independent magmas is removed.

As the effusives represent the same chemical types as the intrusives, all that has been said before of the intrusive rocks is also applicable to them.

3. The original independence of the granitic (including the granodioritic) and of the gabbro-pyroxenitic-peridotitic formations is further corroborated by the fact that they are generally more or less differentiated and rich in facies and in diaschistic veins and dykes. The differentiation of these formations is quite natural if they are considered as original primordial magmas, as well as the absence or small degree of differentiation that is characteristic of such rocks as syenite, diorite, and monzonite, which are themselves differentiation products.

4. Another fact corroborating the original independence of the granitic and the gabbro-noritic formations is the absence of such transitional types as would speak for the production of one of them from the other through differentiation. Amongst regions well known to me personally, I can cite the Caucasus and the Ural Mountains, where these two formations are nearly equally developed and quite independent of one another, and where I have not found transitional types between the two formations in question. On the other hand we know from the studies of Harker[3] that where the granitic magma is mixed with gabbro there are formed such

[1] D. Beljankin, "Petrographical Sketches of the Ilmen Mounts," ii: Ann. Inst. Polyt. St. Petersbourg, vol. xiii, p. 715, 1910.

[2] R. Daly, "Origin of the Alkaline Rocks": Bull. Geol. Soc. Amer., vol. xxi, p. 87, 1910.

[3] A. Harker, *The Natural History of Igneous Rocks*, 1909. Amongst different papers of the author cited in this work see especially "The Tertiary Igneous Rocks of Skye" (Mem. Geol. Surv., 1904).

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[3] A. Harker, *The Natural History of Igneous Rocks*, 1909. Amongst different papers of the author cited in this work see especially "The Tertiary Igneous Rocks of Skye" (Mem. Geol. Surv., 1904).

transitional rocks (Harker's 'marscoite'), to which he gives the very suggestive name of 'hybrid' rocks, showing that their abnormal composition is due to mixture and not to differentiation. The evidence of admixture, the intrusion of one of the rocks into the other in small veins and veinlets, the occurrence of xenoliths of the one in the other, are, in my judgment, facts corroborating the original independence of the two magmas. Were the granite and the gabbro the result of differentiation from another original neutral magma, there would not be evidence of mixture. A very instructive case of identical relations between granite and gabbro is described by Philipp in his recently published study on the granites of the southern Schwarzwald.[1] The members of the gabbro-formation (Philipp's 'gabbroides') occur in separate intrusive bodies and also in xenolithic masses of varying size included in the granitic bodies; while between the granite and the gabbro there is a transitional zone of a mixed gneiss ('Amphibolmischgneiss'), produced by the mixture of the two formations. These data testify to the individuality of the gabbroid and the granitoid magmas, and to their different age. These facts sustain the hypothesis of assimilation, and exclude the presumption that the granites and the gabbroides have been formed by differentiation from a common neutral magma.

Rosenbusch cites of course, according to Lossen, the gabbros and diorites of the Brocken as an example of granitic facies; but my short visit to the gabbros of Harzburg and the Radauthal leads me rather to the conception that these gabbro rocks and the Brocken granites belong to different intrusive bodies connected by intermediary rocks, originated not by differentiation but by assimilation—a view which seems to be supported by the granophyric facies of the gabbro.

The conclusions at which we have arrived is not new. It is well known that as early as 1851 Bunsen[2] was led, by the study of the igneous rocks of Iceland, to the conclusion that they originated through the mingling of two primordial magmas—the normal trachytic (corresponding to our granitic) and the normal pyroxenitic (corresponding to the basaltic). And although the hypothesis that all igneous rocks must be considered as different mixtures of these two is now untenable, the conception that there are two primordial magmas and not one is certainly right. Michel-Lévy[3] has also supported the conception of two magmas. It is true that the two magmas of Michel-Lévy have a far more hypothetical character, and are somewhat indefinite and arbitrary. The alkaline magma comprises the granites as well as the nepheline-syenites, rocks of very different acidity; the magnesian magma is considered to correspond to the peridotites, the lamprophyres, and several other rocks. But even though the exposition of the two magmas of Michel-Lévy is not

[1] H. Philipp, "Studien aus dem Gebiete der Granite und umgewandelten Gabbro des mittleren Wiesentales": Mitteil. Badisch. Geol. Landesanst., vi, i, 1910.

[2] R. Bunsen, "Ueber die Processe der vulkanischen Gesteinsbildung Islands": Pogg. Ann., lxxxiii, p. 197, 1851.

[3] A. Michel-Lévy, "Sur la classification des magmas des rockes eruptives": Bull. Soc. Géol. France, xxv, 1897.

happily stated, from my point of view, the idea itself, that we must admit the existence of two independent magmas from which all igneous rocks originated by differentiation and assimilation, seems to be a true one.

(To be concluded in our next Number.)

III.—On the Structure and Evolution of the Phyllodes in some Fossil Echinoidea.

By Herbert L. Hawkins, B.Sc., F.G.S., of University College, Reading.

(PLATE XIII.)

In all the Regular Echinoids, with the exception of the Cidarids, and in the Irregular Echinoids other than the Clypeastroids and Spatangids, there is a tendency for the ambulacral plates to become crowded together as they approach the margin of the peristome. This is the inevitable result of the continuous formation of fresh plates at the edges of the oculars in the apical system, and their less rapid resorption at the opposite extremity of the ambulacrum. The compression of the ambulacral plates results in a crowding of the pore-pairs in the peristomial region, and this character seems to serve a sensory as well as a motor purpose.

In the Regular Echinoids the muscular effort of mastication is liable to raise the whole body, supported on the teeth, away from the surface on which the food is lying, and so the presence of an increased number of adhesive podia around the mouth is a feature of considerable advantage. Among those forms of the Edentate Irregular Echinoids which are not provided with a labrum, the importance of keeping the mouth firmly applied to the food-bearing surface is yet more urgent, and the increase in the number of the peristomial pores becomes proportionately greater. At the same time, it is necessary that some sensory power should be developed in this region, so that the animal may get an estimate of the quality and character of the food supply. For this function some of the podia would appear to be specialized. In the Spatangids, for instance, the specially large pores round the peristome give exit, according to A. Agassiz (1872, p. 697), to podia with ragged ends. As these cannot exercise an adhesive influence, they may well be sensory in function.

In the Cassidulidæ there is a peculiar series of structures, termed the *floscelle*, which occurs around the peristome. It is composed of five interradial *bourrelets* and five radial *phyllodes*. The bourrelets are formed by the narrowing and thickening of the interambulacra, which form knob-like processes, sometimes slightly overhanging the peristome, and probably homologous in function with the labrum of Spatangids. The phyllodes are expanded, often depressed, leaf-like regions of the ambulacra, and in them there is always some crowding of the pore-pairs. Cotteau (1869, p. 119) states that the size of the phyllodes is in direct proportion to the size of the petals on the adapical surface. This generalization, although in accord with the features of Oolitic forms, is not wholly accurate when applied to Cretaceous and later genera. A plan of the arrangement of the pores in the phyllode of a recent *Echinolampas depressus*, Gray, in my

collection is given in Pl. XIII, Fig. 1. The pores are seen to be roughly triserial in arrangement, but the innermost member of each triad is considerably separated from the other two. In *Echinolampas* the pores are single. In some genera (e.g. *Catopygus*) only the inner series contains single pores, the outer two series being composed of pore-pairs. Although I have been unable to find any evidence on the subject, I consider it at least possible that the inner series of single pores may represent sensory tentacles, while the closely crowded pore-pairs of the outer series give passage to ordinary adhesive podia.

Although the arrangement of the pores is usually easily traceable, it is commonly very difficult to distinguish the plate-sutures near the peristome. By a process seemingly analogous to the obliteration of sutures in the skulls of adult vertebrates, these earlier-formed ambulacral plates tend to become very closely united. Perhaps the mechanical crushing which takes place in the adoral parts of the ambulacra may contribute to this effect. In fossil forms the difficulty is often enhanced by the development of crystalline cleavage-cracks, and accidental fractures. A certain type of weathering, by which the surface of the test is destroyed and all the sutures widened, is serviceable in some specimens, and in default of this a microscopic section will, when viewed under crossed nicols, indicate the position of the separate plates by the varying orientation of the calcite of which they are composed. In every case it is essential that the suturing be studied near the outer surface of the test, as there is often a considerable difference in the degree of plate-crushing developed on the inner and outer regions, that of the inner being usually less pronounced.

The arrangement of the pore-pairs and the tendencies of the plate-crushing are definitely triserial in the peristomial regions of all the forms I have examined, whether recent or fossil. This arrangement is particularly interesting in view of the fact that the plate-crushing in the Holectypoida, the most primitive group of Irregular Echinoids, is always triserial, in whatever part of the ambulacra it may occur. I have recently described this feature in outline (Hawkins, 1910, p. 349), and this paper may be regarded as a sequel to that research. The notation of the plates used here in the descriptions and diagrams is the same as that employed in the paper referred to, and the diagram there given is copied, with additions, on Pl. XIII, Fig. 2.

The phyllode is usually regarded as a structure restricted to the Cassidulidæ (including the Nucleolitidæ), but this is only true of its most complete development. Wherever, in Irregular Echinoids, the pore-pairs show a tendency to become triserial towards the peristome, the elements of phyllode structure seem to be present (e.g. *Conulus*). From the simple and incipient compression of the ambulacral plates in *Pygaster*, every degree of complexity of structure is traceable up to such an elaborate phyllode as that of *Catopygus*. Only in the Clypeastroids and Spatangids (among Irregular Echinoids) is no tendency to phyllode development to be found.

Certain characteristic stages in the formation of phyllodes will now be described, and then the phylogenetic significance of its development will be discussed.

Pygaster semisulcatus (Phill.). Pl. XIII, Fig. 3. Inferior Oolite.

Although not a Cassidulid, and possessing no true phyllode, *Pygaster*, the earliest of the Irregular Echinoids, shows the primitive condition from which this structure was evolved. The ambulacrum tapers gently towards the mouth, but occupies a considerable part of the margin of the peristome. The ambulacrals remain simple primaries from the apex to a point on the adoral surface about half-way between the ambitus and the mouth. There are sometimes slight traces of a sub-petaloid differentiation of the pores on the adapical surface. When the plate-crushing commences it follows the usual Holectypoid plan, every third plate gradually becoming a demiplate. This is plate *c* (see Pl. XIII, Fig. 2). In this way plate *a*, below the demiplate, makes up a larger part of the perradial suture than before, and appears proportionately narrower towards the interradial margin. Plate *b* remains practically unaffected, and the resulting appearance of the ambulacrum is somewhat like that of the greater part of the ray of *Conulus*. There is a tendency for the pore-pairs to become rather widely spaced in the peristomial parts of the ambulacrum in *Pygaster*, and they rarely show any departure from a uniserial arrangement. The traces of displacement which they may exhibit result from a slight perradial shifting of the pores of plate *a*, those of demiplate *c* becoming more approximated to the interradial margin of the ambulacrum.

Galeropygus agariciformis (Forbes). Pl. XIII, Fig. 4. Inferior Oolite.

Galeropygus marks a considerable advance on *Pygaster* in the progress towards irregularity. The ambulacra, which remain apetaloid throughout, are very much narrower in proportion, and, owing to the small size of the peristome, taper considerably in their adoral parts. Perhaps on account of this lateral compression the vertical plate-crushing is carried to a further extent than its contemporary. The first reduction of plate *c* takes place in a position similar to that in *Pygaster*, but almost before this plate becomes a demiplate the interradial extension of plate *a* becomes pinched to a narrow strip. In some cases it is entirely cut off from the interradial margin, and plates *b* and *c* meet round it. In the more extreme cases plates *a* and *c* are almost on the same horizon, and together form a rough parallelogram, with a diagonal sloping interradially and adorally. This crushing, which is the true phyllode structure in a simple form, becomes reduced in intensity near the margin of the peristome, where the plates usually become somewhat irregular primaries. The pore-pairs take on a decidedly triserial arrangement. The pores of plate *a* are, by the more or less complete atrophy of the interradial portion of the plate, compelled to take up a position which is often nearer to the perradial than to the interradial suture. The pores of plate *b*, as if in sympathy, move inwards to about half this extent, while those of demiplate *c* are perforce retained in their usual marginal position. A triad is thus composed of the pore-pairs of plates *a*, *b*, and *c* in descending order. *Galeropygus agariciformis* has all the essential features of phyllode structure, although the ambulacra are neither expanded nor depressed.

The genus in this, as in many other features, shows a close affinity with the Nucleolitidæ, the only important difference being the absence of any sub-petaloid development of the adapical regions of the ambulacra.

TREMATOPYGUS FARINGDONENSIS, Wright. Pl. XIII, Fig. 5.
Lower Greensand.

Although this sub-genus is separated from its Jurassic relatives by a very great interval of time, yet, in default of satisfactory specimens of any of the *Echinobrissi* from the Oolites, I have chosen it as a representative of the Nucleolitidæ (Echinobrissidæ). From the scanty traces of sutures that I have been able to discern in *Echinobrissus scutatus* from the Corallian, there does not seem to be any essential difference in the ambulacral structures. The peculiar character of the incrustation upon the fossils from the dark-red beds of the Faringdon Sponge-gravels renders the sutures, however fine they may be, readily traceable.

There is no appreciable expansion of the ambulacra towards the peristome, and only a trifling amount of depression. The adapical portions are sub-petaloid, but from the apical system to some distance beyond the ambitus the plates are primaries of varying vertical diameter. The actual crushing-point is postponed until a slightly later position than in *Galeropygus*, but anticipatory demiplates (usually of series *c*) sometimes appear spasmodically, though they never occur on the adapical surface. Where the pore-pairs become definitely triserial, the plates are crushed in a manner exactly comparable with that described in *Galeropygus*, but plate *a* is sometimes separated from the interradial margin by a considerable space. A corresponding simplification of the structure is seen in the immediate vicinity of the peristome.

Galeropygus and *Trematopygus* may, judging by the somewhat scanty evidence I have been able to find in other genera, be taken as representing the typical condition of phyllode development in the Nucleolitidæ. On the analogy of the term sub-petaloid as applied to the adapical regions of ambulacra, I suggest the term *hypophyllodal* to express the condition of the adoral parts of ambulacra which have the true phyllode structure as regards their plating, but which are not expanded or depressed.

CLYPEUS PLOTI, auct. Pl. XIII, Fig. 7. Inferior Oolite.

The most striking distinctions between *Clypeus* and *Galeropygus* are found in the extreme petaloid character of the adapical parts of the ambulacra in the former, coupled with the development of a marked floscelle with prominent bourrelets and broad phyllodes near the peristome. In *C. ploti* the ambulacrals retain their primary character until the expansion for the phyllodes begins. Then plate-crushing rapidly supervenes; but, although plate *c* is the first to become compressed, it rarely altogether becomes reduced to a demiplate, while plate *a* becomes almost, if not quite, separated from the interradial margin from the first. Apart from the persistence of the primary character in plate *c*, the plating is quite similar to that in the hypophyllodal forms already described. There is, however, an advance in

the manner of distribution of the pore-pairs. They are triserial, in the order *a*, *b*, *c*; but, while the pairs of *b* and *c* follow the outline of the phyllode more or less definitely, series *a* passes in a straight line, from the point where expansion of the ambulacrum begins, to the corners of the ambulacral margin of the peristome. Thus, in the widest part of the phyllode, these pore-pairs are distinctly separate from the marginal series. They exhibit no difference in size or proportion from the outer pairs.

Clypeus hugi, Agassiz. Pl. XIII, Fig. 6. Inferior Oolite.

The phyllodes of this species differ from those of the last only in their greater expansion. The plating is as nearly identical with that in *C. ploti* as can be expected, and the isolation of the central series (*a*) of pores is no more complete since the peristomial margins of the ambulacra are proportionately wider.

Pygurus michelini, Cotteau. Pl. XIII, Fig. 8. Great Oolite.

The genus *Pygurus* shows the development of the floscelle in a considerably advanced stage. The prominent bourrelets and broad concave phyllodes give a very beautiful appearance to the adoral surface in all the species of the genus. On the adapical surface the ambulacra are broadly petaloid, but are uniformly composed of primaries. No plate-crushing appears until the broadening of the phyllode commences. The result is structurally very similar to that in *Clypeus*, but in the course of their passage across the very wide ambulacra the plates undergo a modification which seems to have an important significance when the structure of the next form (*Catopygus*) is considered. Plate *c* hardly ever becomes an actual demiplate, but is connected to the perradial suture by a very narrow band. Similarly, plate *a* is rarely quite separated from the interradial margin. Its perradial portion is expanded in such a way that, besides reducing the vertical diameter of plate *c* to a very small amount, it exerts a considerable crushing influence on plate *b*, which thus becomes narrow perradially and proportionately broad interradially. In this way the perradial suture comes to be formed of the edges of plates of series *a* more than of those of *b* and *c* combined, while these latter series make up almost the entire interradial margin.

Catopygus carinatus, Leske. Pl. XIII, Fig. 9. Cretaceous.

The phyllodes in this species are the most complex in structure of any that I have seen. Unfortunately the small size of the specimens renders the tracing of the plate-outlines peculiarly difficult. The figure given is, after the manner of a composite photograph, generalized from a series of camera-lucida drawings taken from all five phyllodes in some nine or ten specimens. It may be further mentioned, in support of the figure's accuracy, that it was made before I had adequately studied the simpler types of phyllode, and so is the product of an unbiassed mind. The ambulacra are only slightly sub-petaloid on the adapical surface, so that Cotteau's assertion that complex phyllodes and broad petals are always associated does not apply to this case. The bourrelets are but slightly prominent, and

the phyllodes are almost flush with the level of the adoral surface. The ambulacra, below the sub-petaloid tract, are composed of high primaries until the expansion for the phyllode commences, when plate-crushing rapidly develops, and the average height of the plates is reduced by more than one-half. Plates of series *a* are the first to suffer, and they become separated almost at once from the interradial margin. Plate *c* is immediately afterwards crushed to a demiplate, and the perradial portion of plate *b* is constricted, as in *Pygurus*. The crushing is accelerated to such a degree that the '*Pygurus*-phase' of the structure persists for not more than two of the triple sets of plates. Then plate *a* becomes notably high, and extends laterally less than half the distance to the interradial margin, while not only plate *c*, but also *b*, become reduced to the condition of demiplates. The resulting structure is more apparent from the figure than it could be rendered by description. The phyllode appears as if it were made of two distinct ambulacra, one within the other; the inner of more or less hexagonal plates, and the outer of twice as many long narrow plates. Here and there a slight irregularity in the degree of crushing gives the clue to the origin of this peculiar structure. At about the middle of the phyllode, one of the central series of *a* plates on each side reaches out towards the interradial margin in every example that I have examined. The triserial arrangement of the pore-pairs is hardly appreciable, as the pores of plate *a* are so far distant from those of plates *b* and *c*, which are closely approximated. Moreover, the pores of the separate series are not altogether similar in character. The marginal series of *b* and *c* are paired, and appear as minute circles, but the *a* series of perradial pores are heterogeneous. The upper member of each pore-pair is unusually large, while the lower pore is excessively minute, and often quite invisible. It is in this case that the suggestion seems feasible that the outer pores are for the passage of normal podia, and the inner series for sensory tentacles.

The value of the phyllode in classification.—I have already indicated (Hawkins, 1910) that the ambulacral structures have as great a value in the classification of the Holectypoida as they have among Regular Echinoids. To a large extent the reliability of this feature in the cases mentioned may be ascribed to the fact that it is not one of vital importance to the individual. A multiplication of pore-pairs, similar to that found throughout the greater part of the ambulacra of both groups, could be attained without any interference with the primary character of the ambulacral plates. For this reason, the presence of so persistent a series of peculiarities as those found in the ambulacra of the various groups of Regulares and in the Holectypoida affords a useful criterion of affinity. In the case of the phyllode, the feature of adaptation to surroundings and manner of life is introduced. The urgency of some such provision in the case of edentate forms without labra has been emphasized at the beginning of the paper. But in this case it would seem that the ethological considerations cannot eclipse the fundamental phylogenetic evidence of the structure. One may regard the labiate mouth of a Spatangid and the floscellate mouth of a Cassidulid as being both adaptations to the same necessity.

(This analogy is supported by the presence of 'bourrelet'-like structures in such a genus as *Echinocardium*.)

As far as I have been able to examine the structures, and by inference from the arrangement of the pores in forms whose sutures were indistinguishable, I feel confident in asserting that all phyllodes have the same structure, and the same method of attaining it. In fact, wherever a departure is made from the uniserial arrangement of the pores in Irregular Echinoids (even in the peculiarly aberrant petaloid portion of the anterior ambulacrum in *Heteraster oblongus*), the sequence becomes triserial. When this fact is compared with the extreme differences in structure that Duncan has described in the Regulares (as may be exemplified by a comparison of a compound ambulacral of *Hemipedina* with one of *Strongylocentrotus*), the corollary seems obvious.

The Holectypoida and those Atelostomata grouped as Asternata (see Gregory, 1900, p. 320) form a homogeneous group which, whatever complexity of interrelation they may possess, must be traced back to a common ancestry. The triserial arrangement of the ambulacral structures lends further weight to the arguments given by Bather (1909, p. 106) for the belief that this ancestry is to be sought among the primitive Liassic or Triassic Diademoids. I hope to deal in a future paper with the relations of the various lines of descent which spring from the Holectypoid stock. This paper may be regarded as a preliminary to that more detailed study. Consideration of the other features, apart from ambulacral plating (which all seem to tend towards the same conclusions), must be deferred to the larger paper.

In the Holectypoida themselves, there is little advance in the tendency towards phyllode development until *Conulus* is reached in the Lower Cretaceous. In that genus the pore-pairs near the peristome become triserial, and an approximately hypophyllodal structure is attained. The genus *Pyrina* of the Echinoneidæ appears perhaps in the Jurassic in the form once called *Nucleopygus*, but it attains its chief importance in the Lower Cretaceous. To the embarrassing similarities between *Pyrina* and *Conulus* must be added the fact that the same method of plate-crushing obtains in both genera. The same remark applies to *Echinonëus*, so that the distinction between the Holectypoida and Echinoneidæ becomes wholly arbitrary, at least among their Cretaceous types. The recent discovery by Agassiz (1909, p. 490) of teeth in a young *Echinonëus*, and the description of the teeth of *Conulus* (Hawkins, 1911, p. 70), are further proofs of the close relationship that exists between the two groups.

Galeropygus, of which the earliest known species occurs in the Upper Lias, may well be claimed as the ancestral form of all the non-Holectypoid irregular Echinoids except the Clypeastroids. From this genus there appears to have been a double line of descent. In one series the ambulacra become strongly petaloid, while a well-marked floscelle develops on the adoral surface. This series includes such characteristic genera as *Clypeus* and *Pygurus*, and attained its essential characters quite rapidly, *Clypeus* in particular being abundantly represented by characteristic species in the Inferior Oolite. The

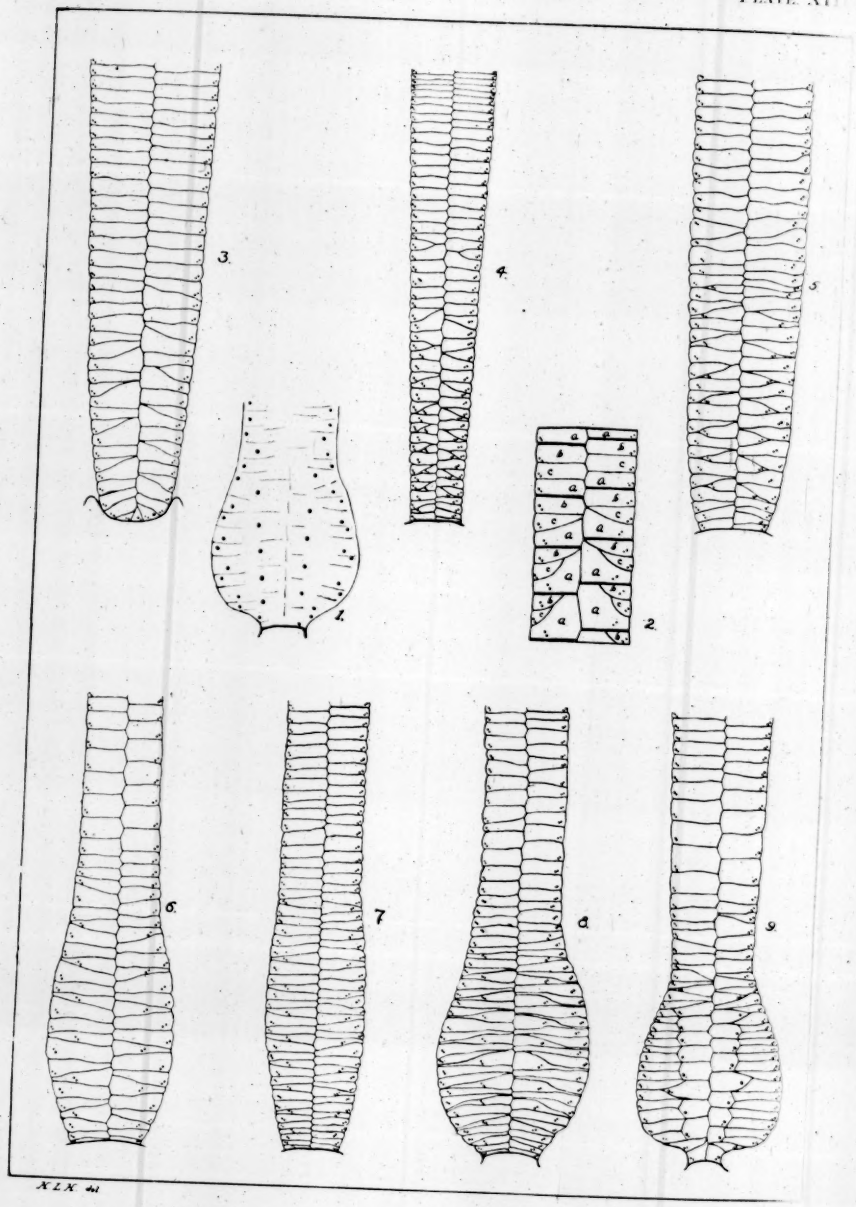
second series is one which retained the more primitive features of *Galeropygus*, with but slight modifications, for a much longer period. This was the family of the Nucleolitidæ (Echinobrissidæ), in which the ambulacra only attain a sub-petaloid condition adapically and a hypophyllodal condition adorally. *Echinobrissus* is a characteristic genus of this group. But while, as far as the evidence seems to point, the *Clypeus–Pygurus* group did not survive the Cretaceous period, the *Echinobrissus* group underwent fresh differentiation in that period, the petals becoming more pronounced and the phyllodes highly specialized. The resulting forms are typified by *Catopygus* and *Echinolampas*.

The product of this Cretaceous development from the Nucleolitidæ is so like that of the Jurassic descendants of *Galeropygus*, on the *Clypeus* line of descent, that both series have been grouped together as the Cassidulidæ. If the interpretation here indicated be correct, this family will need subdivision into, approximately, the Jurassic and Cretaceous Series respectively as distinct families, and would serve as yet another illustration of the principle of 'heterogenetic homœomorphy'. The heterogeneity is, however, more apparent than real, as the *Echinolampas* series is the outcome of the slow development of the *Echinobrissus* series, proceeding along the same lines as those more rapidly traversed by the cognate *Clypeus* series. In passing it is of interest to note that the group which quickly attained a high specialization of petals and phyllodes was comparatively short-lived, while the other group, which appeared at the same time, but which did not reach the *Clypeus* stage of ambulacral complexity until the Cretaceous period, is represented at the present day by members of its simple (*Nucleolites*) and complex (*Echinolampas*) sections.

There yet remains the problem of the origin of the Clypeastroids and Spatangids. In both these large groups some ambulacral plate-crushing occurs (e.g. in *Clypeaster*, *Arachnoides*, and *Echinocardium*), but it never occurs on the adoral surface and is not always triserial. I have reason to believe that this crushing in the petaloid parts of the ambulacra is a secondary development, independent in origin from that of the other Echinoids. The difficulty is encountered when one considers the simplicity of the ambulacra on the adoral surface, where surely the ancestor or ancestors of the groups must have possessed more complex structures. At present, although from other considerations the Clypeastroids seem to show affinity with such a form as *Discoidea*, and the earlier Spatangids with the 'Cassidulidæ', I have found no evidence to indicate the way in which demiplates may be restored to a primary condition, and caused to undergo such remarkable changes in proportion as they show in these groups. Bather (1909, p. 107) discusses the problem with regard to *Orthopsis*, but comes to no definite conclusion. More evidence on the post-larval development of recent forms is necessary before this question will be ripe for solution.

In conclusion I wish to express my indebtedness to Dr. F. A. Bather, F.R.S., for his advice and assistance.

Summary.—The physiological value of the phyllode is considered to be both mechanical and sensory, and the structure of its plating



Arrangement of plates in phyllodes of some Fossil Echinoidea.

is described in several characteristic genera. A distinction is drawn between phyllodal and hypophyllodal structures. A triserial arrangement of the ambulacral pores is shown to correspond with some degree of phyllode development. The importance of the structure from the point of view of classification is discussed. Emphasis is laid upon the close relationship between the Holectypoida and Echinonëidæ. The Cassidulidæ are regarded as a composite group, divisible into two sections (roughly the Jurassic–Cretaceous and the Cretaceous–Recent groups), the former being direct descendants of *Galeropygus*, while the latter, from the same source, slowly attain the Cassidulid character through the medium of the Jurassic Nucleolitidæ.

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EXPLANATION OF PLATE XIII.

The figures are all slightly diagrammatic, and enlarged to the same size regardless of their relative proportions.

FIG. 1. Arrangement of pores in phyllode of *Echinolampas depressus*.
,, 2. Diagram of the principle of Holectypoid plate-crushing.
,, 3. Hypophyllode of *Pygaster semisulcatus*.
,, 4. Hypophyllode of *Galeropygus agariciformis*.
,, 5. Hypophyllode of *Trematopygus farinqdonensis*.
,, 6. Phyllode of *Clypeus kuqi*.
,, 7. Phyllode of *C. ploti*.
,, 8. Phyllode of *Pygurus michelini*.
,, 9. Phyllode of *Catopygus carinatus*.

IV.—A NOTE ON THE GEOLOGY OF THE LITTORAL OF THE GOLD COAST COLONY BETWEEN ELMINA AND SEKONDI, WEST COAST OF AFRICA.

By JOHN PARKINSON, M.A., F.G.S., ETC.

THE following note on the rocks of the shore-line of part of the Gold Coast Colony are a result of a short journey I undertook there in 1910. On that occasion I landed at Cape Coast Castle and travelled westward, staying successively at Elmina, Chama, and Sekondi.

Starting along the coast at Elmina, the coarse granitoid gneiss of Cape Coast Castle, a rock rather poor in ferromagnesian minerals, is left behind at a point some two miles to the east, and is replaced by red grits or arkoses, which have a slight dip to the westward. These beds have frequent ironstone partings, two or three inches in thickness, and are often cross-veined with a similar material: doubtless, therefore, this is a secondary structure due to the deposition,

under favourable circumstances, of iron leached from the beds themselves. A typical example of the ordinary red grit was composed of about 50 per cent. of angular quartz-grains, the greater part of the remainder of felspar, twinned and untwinned, often kaolinized, and similar to the felspars of the surrounding crystalline rocks.

Thin laminæ of kaolin also occur at Elmina, and occasionally pebble beds. The series continues along the sea-front as a broken ridge, and about six miles from the sea, to the northward, rests on the edge of the granitic platform. Here the coast is characterized by isolated flat-topped hills, which appear clearly to owe their structure to marine erosion, and are separated by semi-marshy flats of blackish soil, crowded with shells and impregnated with salt. The shells disappear about three miles from the sea. In these flats the natives dig pits, which fill naturally with water. This on being heated yields the salt. A slight depression would thus reduce the littoral to a series of islands, arranged in rows, approximately parallel to each other and to the sea-front.

The crystalline rocks include a biotite-garnet-granite, with muscovite as an accessory mineral, and having associated with it an aplite, locally pegmatoidal. In this rock microcline and quartz are the two principal constituents, the latter mineral giving evidence of a slight amount of crush. Triclinic felspar is rare and shows, when noticed, symmetrical extinction angles of about 13°, but the twinning is, in many instances, very irregular and partial.

At *Chama*, both on the shore and in the town, a massive gneiss is admirably exposed, and amongst the many varieties is one conspicuously banded. Gneissose veins or dykes cross the foliation of this rock, and, in thin sections, are seen to be identical in structure and composition with the more acid bands. The banding has, in fact, been produced by the injection, in parallel 'sills', of an acid magma, along the foliation planes of a more basic rock. The rocks are of granulitic structure, and usually contain a few flakes of biotite, with sphene and epidote as rare accessory minerals. Untwinned felspar, presumably orthoclase, is common, and occasionally a considerable proportion of microcline. An acid plagioclase is subordinate. The basic part of the gneisses contains much biotite, in flakes occasionally 6 mm. in length.

Two and a half miles west of Chama I found a garnet-hornblende-biotite-gneiss, granulitic in structure and well foliated. Into this rock gneissose dykes are clearly intrusive, and differ only in unessential points from those of Chama itself. It seems clear that at Chama and in the neighbourhood we have a group of biotite-gneisses, of which the acid member is the later, and which are associated with intrusive biotite-granites, aplites, and pegmatites. The strike of the planes of foliation is approximately east and west true.

The *Prah River*, which empties into the Atlantic about a mile to the east of Chama, flows, as regards its lower course, through a well-graded plane of granites and gneisses.[1] These rocks first emerge from

[1] In 1908 the Prah broke through the strip of sand which, as in many West Coast rivers, extended almost entirely across its mouth and enclosed a lagoon. When I saw it in the spring of 1910 this had been repaired by the building-up action of the surf and stood some 15 feet above sea-level.

the alluvium at Krobo, but a short distance from the mouth, and again at Biposo, two and a half hours' journey by canoe, or roughly ten miles. Here occurs a pegmatitic granite, containing a few flakes of biotite, which make a foliation just discernible. Fine-grained 'pepper and salt' gneisses are also conspicuous, in which the content of biotite varies irregularly, producing locally a concretionary appearance. These rocks outcrop at intervals from the river-bed at low-water around the village of Dabuassi, but the best exposures are at the Falls. Here many varieties of gneiss occur, amongst them one containing biotite, subordinate green hornblende, and paler epidote. Quartz, exhibiting some crush shadows, preponderates amongst the colourless minerals, which include a little microcline, a good deal of untwinned felspar, presumably orthoclase, and rare triclinic felspar. Very coarse pegmatite veins and a fine-grained white biotite-granite are associated with the foliated rocks. The black coating, superficially somewhat resembling graphite, which covers these rocks, and effectually masks their structure, is exceedingly well developed at these Falls of the Prah.

Some three and a half miles from Chama (going west) the purple grits come on again in force, dipping almost due south. They are often green and mottled, as are our English slates in some parts of Cornwall, and, approaching Sekondi, are in turn again succeeded by a hornblende-gneiss, cut as before by an acid rock. The more basic type of the former consists for rather more than half its bulk of a green hornblende. A few flakes of elongated biotite, of earlier growth, cut these. The felspar, an acid to intermediate plagioclase, preponderates over the quartz, which, as at Chama, shows crush shadows. Biotite-hornblende-gneisses, in which the proportion of the two-coloured constituents varies considerably, come from the same locality. In these quartz is usually common, exhibiting crush shadows as before, and quartz vermiculé is locally conspicuous. Large orthoclases, often twinned, a little microcline, and triclinic felspars, having symmetrical extinction angles up to 15°, are normal, but, in regard to the last named, it is noticeable that the twinning is often partial. Sphene, apatite, specular iron, pyrites, and iron oxides are the usual accessory minerals.

It is clear that along this part of the Gold Coast littoral, a distance of approximately forty miles, we have—

1. A group of biotite- and hornblende-gneisses, associated with later granites, pegmatites, and aplites.

2. A series of purple grits laid down upon the eroded surface of the crystalline rocks.

3. Evidence of considerable later elevation of the coastline. This elevation, remarked upon by Ellis[1] and suggested by the present writer in the case of Western Liberia, is, in the same manner, clear around the mouth of the Sassandra River, and may tentatively be correlated with the local elevation of the Ijebu Beds of Southern Nigeria (Pleistocene) and Benin Sands (Late Pleistocene to Recent) of the same Protectorate.

[1] Ellis, *The Tshi-speaking Peoples of the Gold Coast of West Africa*, p. 2.

REVIEWS.

I.—A New Vulcanology.

ALBERT BRUN of Geneva may be ranked as one of the most remarkable of contemporary workers in science. At his own expense, and in the intervals of a business career, he has visited the volcanoes of the Mediterranean region, of the Canary Isles, of Java and Krakatoa, and, finally, of Hawaii. Much more than this, he has supplemented mere observation by carefully planned experiments, carried out both in the field and in the laboratory. For such investigations it was necessary that Brun, in addition to his skill as chemist, physicist and geologist, should possess a cool head and undaunted pluck. His simple story of the eruption of Semero, in Java, and the accompanying photographic plates are ample evidence that this condition is fulfilled. Alike as a scientist and as a sportsman Albert Brun is sure of a respectful hearing from British geologists.

And what has led this observer to undertake a self-imposed task of such magnitude? A discovery: the universally accepted aqueous theory of volcanoes broke down when critically tested in the classic region of the Mediterranean; a new vulcanology developed in the mind of the experimenter, and accordingly nothing would suffice but a personal investigation of representative volcanoes in other parts of the globe.

Brun has published many papers since 1901, for the most part in the *Archives des Sciences Physiques et Naturelles*, Geneva, but considering the novelty and importance of his results he is to be congratulated on having gathered his writings together into book form.[1] The material as now presented has been largely recast, and its arrangement is excellent. The whole is easy to read, and although there is no index there is a full table of contents. The photographic plates add greatly to the value and beauty of the volume, and unfortunately also to its price.

We shall now give a brief *résumé* of the matter dealt with in this exceptionally interesting book.

A few definitions of terms are followed by an account of methods employed in taking *temperatures* during the progress of laboratory experiments designed to reproduce volcanic phenomena under conditions favourable to exact observation. Four examples will suffice to illustrate the value of such experiments in fixing temperatures actually encountered in the field—

1. The lowest temperature at which any particular lava can flow at all is given in the laboratory by the temperature at which a thin plate of the same lava (in the same state of crystallization) begins to bend under its own weight.

2. The temperature at which 'ropy structures' form can be ascertained during the artificial production of like structures in a slowly heated block of the lava in question, subjected to a slight lateral pressure by means of a vice.

[1] *Recherches sur l'exhalaison volcanique*, by Albert Brun, Chemist, L.Sc.Ph. Sorbonne, D.Sc.Ph. (*honoris causa*) Geneva. A large quarto volume, 227 pages, 16 text-figures, 27 photographic plates, and 7 panoramas. Price 30 francs.

3. The maximum temperature of a lava containing phenocrysts is given by the melting-point of the most fusible among these phenocrysts (e.g. 1,230° C. in the case of the augite phenocrysts carried by the lavas of Stromboli and Etna).

4. The maximum temperature possible for a volcano is fixed by the '*explosion temperature*' of its magma, that is, by the temperature at which its magma emits gas sufficiently rapidly to undergo a sudden expansion. Acid lavas have a sharply marked explosion temperature; basic lavas, which are more fluid, begin to give off gas to an appreciable extent as soon as they soften, and by careful heating it is possible to avoid actual explosion.

The laboratory determinations of temperature referred to above can be supplemented in the field, and this becomes essential in the investigation of fumaroles. The methods employed in such cases are given in outline in the book.

The results of about seventy experiments dealing with the temperature constants of minerals are tabulated. In keeping with the almost aggressive self-reliance of the author the recent work of the American school is not taken advantage of; this is unfortunate, and one has to turn to the original papers to realize the following correspondences:—

	Melting-point (° C.).
Anorthite.	
From Idsu, Japan	1,490, 1,510, 1,520 (Brun, 1902).
Synthetic	1,544, 1,547, 1,550, 1,562 (Brun, 1904); 1,532 (Day & Allen, 1905).
Albite.	
From Viesch	1,250 (Brun, 1902).
Synthetic	1,230 (the value obtained by extrapolation; no definite melting-point ascertainable, 'melting' being spread over a temperature interval of about 150° C.; Day & Allen, 1905).
Pseudo-Wollastonite	1,515 (Brun, 1904); 1,512 (Allen & White, 1906).

These results show that Brun was much in advance of his time in the accurate determination of geophysical temperate constants. In other cases where comparison is possible there are somewhat important discrepancies; these are no doubt due in part to chemical peculiarities in the naturally occurring minerals experimented on by Brun, but their occurrence makes the omission of the American data all the more regrettable.

The results of thirty-five temperature experiments with lavas may be illustrated by giving two examples.

Kilauea. Basaltic glass with very few crystals. On account of this scarcity of crystals the lava is extremely fluid at moderate temperatures; at the same time, to obtain initial deformation one must heat to a higher temperature than in the case of lavas from other volcanoes: up to 1,100° C. the colloid is unusually resistant, but above this it becomes very fluid. According to different experiments the temperature of formation of a ropy surface is 1,072° C. or 1,073° C., and the temperature at which the lava flows freely with emission of gas is 1,116° C. or 1,159° C. The "hairs of Pélé" form at 1,120°–1,160° C.

Krakatoa. Green obsidian mixed with the pumice of 1883. The explosion temperature for any particular specimen is very well

defined. For commonly occurring types the following values have been obtained: 826° C., 861° C., 877° C., 883° C., 886° C., 888° C., 896° C.

It is thus tolerably certain that the temperature of the Krakatoa magma in the paroxysm of 1883 was approximately 880° C.

A contrast which presents itself in the behaviour of rocks in general when heated allows Brun to divide them into two classes, the active and the dead. The active rocks include only comparatively recent, unoxidized, volcanic products; all other rocks are dead.

Active basic rocks when melted liberate gas and volatile salts, which latter condense to form white fumes. The liberation of gas and vapour often swells the molten mass to such an extent that it overflows the crucible, furnishing a miniature fuming lava-flow. By cooling and reheating it is sometimes possible to repeat this experiment several times. A block of the 1904 lava of Vesuvius was still 'active' after five such heatings.

Active acid rocks are much more violent when heated and give rise to veritable explosions.

Dead rocks, such as schist, granite, or gabbro, behave quite differently. On heating they give off gas, and then at a higher temperature melt quietly. There is no trace of the magnificent expansion characteristic of the active rocks.

The tremendous pressure developed on heating obsidian to its explosion temperature can be illustrated by performing the experiment on a piece of obsidian enclosed in a box of refractory steel. When the explosion temperature is reached the box is burst and the magma is extruded in a manner which recalls the formation of the spines of Montagne Pelée and Merapi (Java).

As a general rule a magma, at any rate when once it has been extruded at the surface, is markedly heterogeneous in regard to its gas-producing capacity. On a field of lava there are comparatively few points from which fumes issue in really great abundance. Again, certain thin bands in obsidian may flash up into froth on heating while other adjoining layers remain glassy.

The volume of gas liberated in exploding an obsidian can be ascertained approximately from a comparison of the density of the obsidian with that of the resultant pumice. To take two striking examples: Lipari obsidian of density 2·358 corresponds with a pumice of density 0·224; and Krakatoa obsidian of density 2·36 corresponds with a pumice of density 0·416. In the case of Krakatoa this means that 1 kilog. of the obsidian must yield 1,577 c.c. of gas at 880° C. (the explosion temperature), or 373 c.c. reckoned at 0° C.

Here Brun turns aside to give an account of the collection, extraction and analysis of the various volcanic gases.

Collection in the field. There are two main methods. Wherever possible the gases are pumped through a system of tubes, which may be made of lead where the temperature is low or of glass where it is high. A rubber pump is used, and the gases, once they are cooled down, are collected over mercury, or, as the case may be, examined in a hygrometric chamber. The glass tubes employed are each a metre long, and sometimes as many as forty of them have been connected end to end, their joints wrapped in sheets of lead or aluminium bound

with iron wire. This method has the advantage of providing as much gas as can be stored. The glass tubes can afterwards be washed to allow of an estimation of the solid material of the fumes. Where haste is essential a vacuum tube can be carried to the desired point, and there opened, charged and resealed.

Extraction of gases in the laboratory. A vacuum apparatus is employed, and this, with the methods of gas analysis, is described in the book. Very numerous experiments show that such water as is given off is always liberated before the explosion temperature is reached; it is largely dissipated at 150° C.; at 300° C. there is none left. Certain old volcanic glasses are found to be exceptionally hydrous.

The main volatile constituents liberated from active rocks at the explosion temperature are—

Gases.—Chlorine, hydrogen chloride and oxides of carbon.

Solids.—Chlorides of the alkali metals of ammonium and to a small extent of ferrous iron.

Sulphur and its compounds are almost always inferior in amount to chlorine and the oxides of carbon.

Details of the volatile constituents extracted at the explosion temperature *in vacuo* are given for the lavas of about fifty distinct volcanoes, embracing every part of the earth. The relative proportions vary greatly, as will appear from the following table:—

		Stromboli.	Vesuvius.	Kilauea.	Semëro.	Krakatoa.	Arran (Pitchstone).
Volume of gas in c.c. (0° C., 760 mm.) per kilog. of lava		266	397	295	139	498	457
NH_4Cl in mg. per kg.		13·5	17	12	20·5	49	45·7
Other volatile chlorides in mg. per kg.		243	3500	50	143·5	—	—
Hydrocarbons		—	—	very volatile	—	—	volatile
Percentage volumes of each gas.	Cl_2	12·8	4·2		18·2	59·64[1]	absent
	H Cl	2·0	trace	trace	9·2	11·63	5·8
	SO_2	4·5	3·35	1·7	absent	7·99	46·7
	CO_2	60·2	66·30	50·8	47·2	6·73	
	CO	11·47	26·15	17·3	18·0	4·78	18·2
	CH_4	1·60		—	—	—	—
	H_2	0·5		28·5	3·35	—	—
	N_2	6·93		1·2	3·35	8·73[2]	—
	O_2	—	—	—	—	0·50	—
	Fetid combustible residue	—	—	—	—	—	29·3
		100·0	100·0	99·5	99·3	100·0	100·0

[1] With traces of S_2Cl_2.

[2] N_2 and other gases.

Water does not enter into the results given above, since these are wholly concerned with volatile matter released at the explosion temperature. The Arran pitchstone is regarded as a typical hydrated obsidian of moderate antiquity. It has much water, which it loses almost entirely at 200° C., whereas its explosion temperature is about 900° C.

It is important to realize that the anhydrous gases which are liberated from a lava heated *in vacuo* to its explosion temperature, are more than sufficient to explain the paroxysmal phenomena observed in nature. We have already seen that in the Krakatoa eruption of 1883 every kilogram of obsidian involved gave about 373 c.c. of gases (0° C. and 760 mm.). In the laboratory experiments 457 c.c. have been obtained, not to mention 45·7 mg. of ammonium chloride.

To bring these results into closer touch with nature is the next step. Brun finds that freshly fallen ashes contain soluble chlorides, including ammonium chloride and greasy hydrocarbons, which later can be extracted with chloroform. They also always give an acid reaction. It thus appears that the stony matter of the ashes is mixed with the same volatile products as are generated in the artificial distillation of a magma under anhydrous conditions *in vacuo*. Samples of the 1906 ash of Vesuvius, collected during the eruption at thirty-five different localities, contained from 1 to 1½ per cent. by weight of soluble salts, about equally proportioned between the sulphates and the chlorides. The abundance of sulphates is a feature of which no mention is made in connexion with the laboratory experiments.

The salts deposited by dry fumaroles and on the walls of craters are found to agree with those associated with ashes.

Secondary exhalation.—A specimen of lava, which has already been heated to its explosion temperature *in vacuo*, will give a fresh supply of gas if oxidized by heating to a moderate temperature in air or oxygen or by melting with some such reagent as *ferric oxide*. The gases produced under these circumstances constitute what Brun appropriately terms the secondary exhalation. A few examples are given in the subjoined table. It must be clearly understood that the secondary exhalations here tabulated are *additional* to the primary exhalations previously quoted.

		Stromboli.	Vesuvius.	Kilauea.
Volume of gas in c.c. (0°, 760 mm.) per kilog. of lava		512	643	62
Percentage volumes of each gas	Cl_2	trace	4·6	—
	SO_2	48·16	1·53	31·0
	CO_2	78·58	89·60	69·0
	N_2	3·26	4·27	—
		100·00	100·00	100·0

It may be pointed out that the emission of a secondary exhalation as a result of atmospheric oxidation does not necessarily entail any expansion at all, since carbon dioxide and sulphur dioxide occupy no greater volume than their contained oxygen.

Gas generators.—Brun suggests that the volcanic exhalations result in the main from reactions between silico-chloride of calcium ($Si O_3 Ca_2 Cl_2$), nitride of silicon and various hydrocarbons. Such speculations are of necessity unconvincing, but they are supported by a large number of strikingly interesting experiments. In regard to the origin of sulphur and its compounds in volcanic exhalations he expresses no definite view, but at the same time he has several important observations to record respecting the mode of occurrence of the element in nature.

An effect of high pressure.—The gases obtained experimentally *in vacuo* are the same as those which actually issue from volcanoes. There is only one exception: carbon monoxide, a characteristic gas of the laboratory experiments, is extremely rare in nature. Its absence may be accounted for on two heads. In the first place it is easily burnt to carbon dioxide on contact with air, and in the second place, according to Briner, it readily decomposes to carbon dioxide and carbon on heating to 300° C. at 600 atmospheres. It is quite possible, therefore, that the rarity of carbon monoxide in volcanic exhalations is due to the high pressures ruling during the emission of the latter.

E. B. Bailey.

(To be concluded in our next Number.)

II.—Canadian Geological Survey.

Reports on parts of the North-West Territories to the west of James Bay and south of Hudson Bay, have been prepared by Mr. W. McInnes and Mr. A. W. G. Wilson (1910). The rocks encountered during their explorations and traverses include Archæan, Lower Huronian (?), Silurian (Niagara), Pleistocene, and later deposits. A list of Silurian fossils obtained along the Winisk River is given on the authority of the late J. F. Whiteaves. Observations are recorded on the natural history, climate, archæology, etc.; and there are lists of recent land and freshwater mollusca collected by Mr. Wilson and named by Whiteaves.

The "Geology of the Nipigon Basin, Ontario", by Mr. Wilson (Memoir No. 1, 1910), is illustrated by a map containing a good deal of detailed work, as well as data obtained by traverses. The rocks are all grouped either definitely or doubtfully as pre-Cambrian. The greater part of the district is underlain by Laurentian gneisses and batholithic invasions of granite, which penetrate an apparently older series of greenstones and schists, classed as Keewatin. Infolded with the Keewatin rocks, and probably belonging to the higher portion of the series, is an Ironstone formation. The Keewatin Series also contains bands with quartz stringers and veins that yield small values in gold. These more ancient rocks are all intensely metamorphosed, and the prevailing structures are nearly vertical. Upon them rest the Keweenawan (Nipigon formation), consisting of conglomerates,

sandstones, shales, and dolomitic limestones. The later rocks are diabase, and they extend in patches over a large area.

A "Preliminary Memoir on the Lewes and Nordenskiöld Rivers Coal District, Yukon Territory", by Mr. D. D. Cairnes (Memoir No. 5, 1910), is descriptive of a varied series of formations, Pre-Ordovician, Devonian (?), Carboniferous (?), Jurassic or Cretaceous, Tertiary and Quaternary. Two horizons of coal are recorded in the Jurassic or Cretaceous; the higher beds, worked at the Tantalus mines, being the more valuable. The seams are from 3 to 7½ feet thick.

"The Edmonton Coal Field, Alberta," is described by Mr. D. B. Dowling (Memoir No. 8 E, 1910), and he estimates that, if mined economically, the available quantity of coal is about 80 million tons.

III.—Cleveland Ironstone and Iron.

MR. J. E. STEAD, F.R.S., read a paper before the Cleveland Institution of Engineers (Middlesbrough, 1910) on the Cleveland Ironstone and Iron. The author deals with the micro-structure of the Cleveland Stone, a subject illustrated by twelve photographic plates. Silica is present in the oolitic iron-ore in concentric layers, but no examples of oolitic limestone with silica envelopes could be procured, although the grains in the Pickering limestone of Corallian age contain much silica. Concentric layers of iron-pyrites (with nickel and cobalt) occur in the oolitic 'sulphur bed' of the Eston ironstone. A piece of petrified wood in the Eston ironstone contained 90 per cent. of calcium phosphate and 10 per cent. of a peat-like substance. In the Rosedale ironstone an ammonite was found in which the segments and outer shell had been considerably changed to ferrous carbonate.

In seeking for portions of the original rock Mr. Stead found what he believes to be a representative of it "imprisoned in the vertebral column of a *Plesiosaurus*". Analyses are given of the bone and of the substance inside it. That of the latter, which consisted of oolite closely resembling the ironstone itself, was as follows:—

	Dried at 212° F.
Ferrous Carbonate	15·58
Iron Pyrites	0·82
Alumina	7·00
Silica	19·80
Calcium Carbonate	51·16
Calcium Phosphate	2·53
Magnesia	1·67
Organic matter, etc.	1·44
	100·00
Iron	7·90
Sulphur	0·40
Phosphoric Acid	1·16

One of the oolite grains shown in pl. xii. and representing rock-material after treatment with hydrochloric acid, had evidently consisted mainly of calcite, but near the exterior there were to be seen a few concentric siliceous layers. Mr. Stead asks: "Does this single grain not indicate an uninterrupted change, and point to a process which, if continued, would have resulted in the complete

replacement of the carbonate of lime by silica and ferrous carbonate? Considering the fact that the imprisoned substance contains an excess of carbonate of lime and very little ferrous carbonate, but in other respects corresponds to the analysis of the Cleveland ironstone, are we not justified in accepting the evidence as going far to prove that the original deposit was really siliceous and aluminous limestone, and that not only ferrous carbonate, but ferrous silicate in solution, has taken the place of carbonate of lime, as Dr. Sorby maintains, and that co-incidentally silica in solution has passed from the mass of calcareous and siliceous mud which surrounded the original, nearly pure limestone concretions, and was then deposited in concentric layers?"

IV.—Indian Geological Survey.

THE Memoir on "The Geology of Northern Afghanistan", by Mr. H. H. Hayden, Director (Mem. Geol. Surv. India, vol. xxxix, pt. i, 1911), contains observations made "during a short tour undertaken primarily for the investigation of economic questions". The author describes the physical features and main geological structure of the country, and deals with a varied series of rock-formations. The age of the oldest, "Metamorphic and Crystalline Series," is practically undetermined, but it includes limestone, yielding ruby and rarely sapphire, and this may be of Devonian age. There is evidence of Lower Palæozoic rocks, of Devonian, Carboniferous, Permo-Carboniferous (Fusulina limestone), Triassic, Jurassic, Cretaceous, Tertiary, and Pleistocene. The facts gathered by the author, and previously by C. L. Griesbach (1880–8), lead to the conclusion that the "country is divisible into two stratigraphical provinces, one of which is represented only in Eastern Afghanistan, while the other comprises by far the greater part of the country and embraces most of the northern and western districts. The affinities of the former province are with the Himalayan area, whereas those of the latter are with Western Asia and also to some extent with Europe. The mutual separation of the two provinces seems to have taken place towards the end of the Carboniferous period". The memoir is illustrated by a geological map and many striking views of stratigraphical and rock features, including a recumbent fold, overthrusts, dome-structure, unconformities, etc.

V.—United States Geological Survey.

BULLETIN 433, 1910, consists of a report on the "Geology and Mineral Resources of the Solomon and Casadepaga Quadrangles, Seward Peninsula, Alaska", by Mr. P. S. Smith. In this work we have descriptions, with geologic and topographic maps, of portions of Seward Peninsula on the borders of Norton Sound in Western Alaska. A small and useful geologic map of the entire peninsula is also given, and this shows a pre-Ordovician series of gneisses, limestone, and schists, the Kigluaik group; a series of unfossiliferous schists, and of limestones which yield Ordovician and possibly Silurian fossils; and a newer limestone "from which Carboniferous or Upper Devonian fossils have been obtained". There are also andesites of uncertain age, granites of later date, some late

Mesozoic or Tertiary strata, as well as Pliocene and later deposits. Gold has been obtained in profitable quantity from the Hurrah quartz mine, the associated slaty rocks being possibly of Devonian age; but most of the gold is obtained from placer deposits, of which detailed accounts are given. Among the metamorphic rocks there is great complexity of structure, recumbent overturned folds and extensive thrust-faulting being described.

Bulletin 435, 1910, records "A Reconnaissance of parts of North-Western New Mexico and Northern Arizona", by Mr. N. H. Darton. The country here described and shown on a geological map extends along the borders of the railway from Albuquerque on the east to Peach Springs and Kingman on the west. A variety of formations is exposed—Pre-Cambrian, Cambrian, Devonian, Carboniferous, Triassic, Cretaceous, Tertiary, and Quaternary. The region lies mostly in the plateau province, and it includes the Grand Canyon in North Central Arizona, where the ground rises to more than 8,500 feet and the deep gorge is at its base 2,436 feet above sea-level. Some effective views are given of the Canyon, of pre-Cambrian granite with nearly vertical jointing, of the Wingate Sandstone (Triassic), of Bad Lands, a typical desert valley, and of a recent volcanic cone, etc. In the 'petrified forest' of Arizona, which is of Triassic age, the logs occur in a conglomeratic sandstone, the 'Lithodendron formation', but as the beds are eroded the silicified trunks accumulate at the surface at various levels. The principal species, *Araucarioxylon arizonicum*, was described by Mr. F. H. Knowlton. The higher portion of the Trias, known as the 'Painted Desert formation' on account of its banded and brilliantly coloured sandstones, may possibly include beds of Jurassic age.

The principal mineral resources of the area are coal and copper; but asbestos, gold, gypsum, limestone, and building-stone are of importance.

Bulletin 425 deals with the practical question of "The Explosibility of Coal Dust", by Mr. G. S. Rice and others. Bulletin 429 treats of "Oil and Gas in Louisiana, with a brief summary of their occurrence in adjacent States", by Mr. G. D. Harris. The author deals with the occurrence of oil and gas (1) in "Saline Domes", the nuclei of which are generally found to be made up of rock-salt, while oil and gas have been concentrated in enormous quantities, the surrounding territory being barren, and (2) in "Stratum oil and gas fields", where the materials are coextensive with certain widespread geological strata, though occurring in commercial quantities only in areas where the structure is favourable.

A "Preliminary Report upon the Oil and Gas developments in Tennessee" has been prepared by Mr. M. J. Munn for the State Geological Survey of Tennessee (Bulletin 2E, 1911).

VI.—Brief Notices.

1. Iowa.—In an account of "The Pleistocene Deposits in Warren County, Iowa" (Univ. Chicago Press, 1911), Mr. J. L. Tilton discusses the physical changes which the area has undergone in Quaternary times. The pre-Glacial topography was wholly unlike that of the present; it was almost entirely obliterated by the "sub-Aftonian

drift" (Boulder-clay); a new topography was developed when the "Aftonian Interglacial deposits" were accumulated; and the main features then produced are those of the present day. Minor features were affected by a partial mantling of Kansan drift, by later erosion, and also by local deposition of loess.

2. California.—A well-illustrated report on "The Geomorphogeny of the Sierra Nevada north-east of Lake Tahoe" has been prepared by Mr. John A. Reid (Univ. California Public, vol. vi, p. 89, 1911).

3. Geology of the Argentine Republic.—A memoir entitled "La Precordillera de San Juan y Mendoza", by Dr. Richard Stappenbeck, is descriptive of the fourth section of the Geological Map, which embraces a belt of country extending from San Juan northwards to Jachal and southwards to Mendoza, along the western borders of the Republic. The formations represented on the map (scale 1:500,000) include Pre-Cambrian (?), Lower Silurian (or Ordovician), Devonian, Carboniferous, Permian, Trias, Rhætic, Jura-Cretaceous, various Pleistocene and recent deposits, and Igneous rocks. In the memoir the various rocks are described, together with the structure of the country; lists of fossils are given, and the mineral products and underground waters receive due attention. The memoir contains a number of illustrations of the geological features, and is published as volume iv, No. 3 of the Anales de Ministerio de Agricultura (Sección Geología, Mineralogía y Minería), Buenos Aires, 1910.

4. South Australia.—Mr. Walter Howchin has described a "New and Extensive Area of Permo-Carboniferous Glacial Deposits" in the country between Strathalbyn and Port Elliot, south of Adelaide (Trans. Roy. Soc. S. Australia, vol. xxxiv, p. 231, 1910). The subject is well illustrated by a geological map and fourteen plates.

5. Measurements of the Increase of Temperature in Bore-holes (Trans. Inst. Mining Engineers, vol. xxxix, 1910).—In this paper Messrs. J. Königsberger & M. Mühlberg express the view that "Various causes exist (together or separately) for an abnormally elevated temperature in the deeper-lying portions of the earth's crust: the increase of plutonic influences (comparatively recent intrusive bodies); ores in process of oxidation; minerals, such as anhydrite, in course of hydration; sulphur deposits; bituminous minerals, especially petroleum; coals not yet transformed into anthracite; thermal springs"; etc. The authors suggest that an abnormally elevated temperature may be "an indication of the said more or less valuable materials", and that for depths of 600 feet or more, "Temperature-measurements should form part of the routine of boring, whether they prove of immediate practical value or not."

6. Sussex.—In an account of "The Older Prehistoric Races of Sussex" (Eastbourne Nat. Hist. Soc., 1910) Mr. W. J. Lewis Abbott draws attention to the plateau or eolithic implements, "relics of Pliocene man," found in the county; and to a particular discovery of Palæolithic implements north-east of Hastings, many examples being identical with forms found in the French caves of Magdalenian age, and termed by him "Fairlightian". Mr. Abbott expresses his conviction that the implements of Cissbury (long classed as Neolithic) are of Palæolithic age.

REPORTS AND PROCEEDINGS.

Geological Society of London.

I. *March* 22, 1911.—Professor W. W. Watts, Sc.D., M.Sc., F.R.S., President, in the Chair.

The following communications were read:—

1. "On some Mammalian Teeth from the Wealden of Hastings." By Arthur Smith Woodward, LL.D., F.R.S., F.L.S., Sec.G.S.

Mr. Charles Dawson, F.S.A., F.G.S., has obtained two imperfect molars, apparently of *Plagiaulax*, from beds of grit in the Wealden near Hastings; and his associates in the work of exploration, Messrs. P. Teilhard de Chardin and Félix Pelletier, have found a well-preserved multituberculate molar of the form named *Dipriodon* by Marsh. These specimens are described.

Mr. Dawson said there were three horizons where bone-beds constantly occur: (1) in the Upper Tunbridge Wells Sands just below the Weald Clay (being the true 'Tilgate Grit' of Mantell); (2) at a great depth below the former, at the base of the Wadhurst Clay, in the blue clay above, and sometimes associated with, the thick bed of calcareous sandstone ('Blue Stone'); and (3) about 26 feet below No. 2 (at Hastings), at the top of the Ashdown Sand; it is less fossiliferous than either of the former, and is usually associated with bands of calcareous sandstone. So far, mammalian remains had not been discovered in No. 1; Nos. 2 and 3 had yielded the teeth ascribed to *Plagiaulax*, and now No. 3 had also furnished *Dipriodon*.

2. "Some Observations on the Eastern Desert of Egypt, with Considerations bearing upon the Origin of the British Trias." By Arthur Wade, B.Sc., F.G.S.

This paper deals chiefly with phenomena observed in the Eastern Desert of Egypt, bordering the Gulf of Suez and that part of the Red Sea which is adjacent to its junction with the Gulf. The mounds of igneous debris which flank the coastal hill-ranges are described, and their origin is discussed and connected with the raised-beach phenomena present in the area. The distances to which fragments of igneous rock derived from these hills have travelled in Egypt are shown.

The shore-sands are next dealt with, and their origin ascribed mainly to the breaking down of local rocks, and not necessarily to the denudation of Nubian Sandstone areas as has been supposed. In the marly beds connected with the recent shore-deposits, tiny dolomite-rhombs, similar to those found by Dr. Cullis in the Keuper Marls, are present. Some effects of wind-blown sand are described, especially the wedging of the sand-grains into cracks produced by other forces of disintegration.

Deposits of rock-salt and gypsum are being laid down at present in the area. The alteration of the calcium carbonate in recent shell-beds to gypsum, with the accompanying destruction of organic remains, is noted; and its significance with regard to the origin of gypsum-beds and the concurrent absence of fossils in some of the older series of strata is pointed out. Analyses of different deposits are given, and the presence of sodium carbonate and epsomite crystals is proved in

the encrustations upon recent fossil shells. The characters of the massive older gypsum and rock-salt deposits are described, together with the distribution and lithological changes in the beds when traced across the area by means of borings and outcrops. The origin of the gypsum series is shown to be connected with inland salt-lake conditions, and evidence is presented which suggests that these conditions were contemporaneous with the Oligocene continental period in Egypt, and with the formation of the well-known beds of the Fayûm in the Western Desert. A sketch-map showing, for the first time, the geology of the island situated in the mouth of the Gulf of Suez accompanies the paper.

3. "Faunal Horizons in the Bristol Coal-field." By Herbert Bolton, F.R.S.E., F.G.S., Curator of the Bristol Natural History Museum.

The author has been engaged for three years in the examination of the Coal-measures of the Bristol Coal-field, and has determined the existence of faunal horizons at the collieries of South Liberty, Easton, Hanham, Speedwell Deep, and Coalpit Heath in the Bristol and Gloucestershire area, and at Ludlows, Middle Pit, Tyning, Wellsway, Writhlington, Foxcote, Dunkerton, Newbury, and Mackintosh collieries in the Radstock area. A measured section of 760 feet between the Ashton Great Vein and the Bedminster Great Vein at the South Liberty Colliery, Bristol, has been examined in detail, and four faunal horizons discovered. These horizons occur at 134, 284, 286, and 637 feet respectively below the Bedminster Great Vein. In every case the fauna was marine in character, and the author's work shows that the Ashton and Bedminster Series of Bristol, the Coalpit Heath and Parkfield Series of the northern part of the coal-field, and the Vobster Series of Radstock are all characterized by a fauna agreeing with the typical fauna of the Lower Coal-measures of the coal-fields of the Midlands and of Lancashire and Yorkshire.

Species of *Carbonicola* are rare, while the Cephalopod and fish fauna is poor. The Second or Farrington Series of the Upper Coal-measures has yielded *Lingula mytiloides*, several species of Ostracods, four species of *Anthracomya*, and scales of *Strepsodus sauroides*. *Cœlacanthus elegans* has been found in the First or Upper Radstock Series. The presence of marine phases in the Bristol Coal-field is confirmatory of the evidence obtained by Mr. W. H. Dyson in the Yorkshire Coal-field, where an extensive fauna has been found in four horizons above the Barnsley Coal.

In the Bristol, as in the Yorkshire Coal-field, the marine fauna undergoes no marked change in its upward range, specific identity being retained in the uppermost horizons, while new species are rare.

Insect-wings referred to the genus *Geneutomum* have been found at one horizon in the South Liberty Colliery, Bristol, 637 feet below the Bedminster Great Vein; while the rare Phyllopod, *Leaia leidyii*, var. *salteriana*, hitherto only known from the Lower Carboniferous of Fifeshire, was found in great abundance in the roof-shales over the High Vein of the Parkfield Series at Coalpit Heath Colliery. Frequently the specimens occurred in dense clusters, the latter being distributed over the surface of the slabs of shale. The smallest are not more than 2 mm. in length, the largest reaching 8 mm.; hundreds

of examples were found. The total number of species now recorded by the author from the Bristol Coal-field amounts to seventy-four; they are as follows: Echinodermata, 1; Vermes, 2; Brachiopoda, 9; Pelecypoda, 25; Gasteropoda, 13; Cephalopoda, 8; Arthropoda, 6; and Pisces, 10.

II. *April* 5, 1911.—Dr. C. W. Andrews, B.A., F.R.S., Vice-President, in the Chair.

The following communications were read:—

1. "Trilobites from the *Paradoxides* Beds of Comley (Shropshire)." By Edgar Sterling Cobbold, F.G.S.; with Notes on some of the Associated Brachiopoda by Charles Alfred Matley, D.Sc., F.G.S.

The author describes and illustrates the type-specimens of *Paradoxides Groomii*, Lapworth, 1891, and the associated Trilobites from the basement beds of the Middle Cambrian of Comley Quarry. Among the latter there are two or three other species of *Paradoxides*, represented by fragments insufficient for specific determination; also a species of *Dorypyge* allied to *D. oriens*, Grönwall, and one of *Conocoryphe* allied to *C. emarginata*, Linnarsson. He also describes some of the Trilobites from a higher horizon containing *Paradoxides Davidis*, Salter, and *P. rugulosus*, Corda; and notes on the Brachiopoda from this horizon are contributed by Dr. Matley.

A complete list of the Trilobites hitherto identified from the local Cambrian deposits is given, arranged under the following provisional faunal groups:—

MIDDLE CAMBRIAN.

Davidis Fauna from the Shoot Rough Road Beds.
Groomii Fauna from the Quarry Ridge Grits.

LOWER CAMBRIAN.

Protolenus–Callavia Fauna from the Grey and *Olenellus* Limestones.

The author draws attention to the great divergence between the two last-named faunas, and also describes the recently exposed evidence of the accompanying physical break between the Middle and the Lower Cambrian beds of the locality: arguing from the analogy afforded by American deposits that, if the *Olenelli* with telson-like pygidia were ever present in Shropshire, their place in the local series would be among the strata cut out by the unconformity.

2. "The Stratigraphy and Tectonics of the Permian of Durham (Northern Area)." By David Woolacott, D.Sc., F.G.S.

The Permian strata of Durham and Northumberland lie unconformably on a basin of the Coal-measures. They can be divided as follows:—

(4) Upper red beds with salt and thin fossiliferous Magnesian Limestones (only exposed in the south of Durham). 300 feet.

(3) The Magnesian Limestone.

(*a*) Upper.

1. Yellow bedded limestone of Roker. 100 feet.
2. The concretionary limestone of Fulwell and Marsden—a series of concretionary and non-concretionary limestones and marls. 150 to 250 feet.
3. The Flexible Limestone. 10 to 12 feet.

(*b*) Middle.

(1) Unbedded (as a rule), highly fossiliferous (often) limestone of Claxheugh, Tunstall, etc. Forms a ridge of high ground and reaches a thickness of 300 feet. Often brecciated and entirely changed in character—rendered more calcareous and fossils obliterated.	replaced on the east by	Bedded yellow, non-fossiliferous limestones of the northern end of Marsden Bay and the coast from Hendon to Seaham Harbour. Often highly brecciated. 150 feet.

(*c*) Lower. Bedded brown limestones of Frenchman's Bay, Houghton, etc. Upper beds often disturbed. 40 to 200 feet.

(2) The Marl Slate. 3 feet.

(1) The Yellow Sands, from 0 to 150 feet.

These beds, which vary much in thickness, lie in North Durham in the general form of a syncline beneath Sunderland.

The unfossiliferous Yellow Sands are probably a deltaic formation reassorted by wind, the other beds being the result of deposition in an inland sea undergoing desiccation. The magnesium carbonate existed in the waters of the sea, and was either deposited along with the calcium carbonate, or introduced by seepage when the beds were being laid down.

Great changes in the amount and distribution of these carbonates has, however, taken place since deposition. The cellular structures that occur in the limestone can be classified as follows: (1) concretionary-cellular; (2) negative breccia; (3) solution-cavities; and (4) fractured cellular. Most of them have been produced by the leaching-out of the magnesium carbonate (dedolomitization), or of both that and calcium carbonate. In some cases the rock has been rendered crystalline, as well as more calcareous, and the fossils have been obliterated. They do not afford any proof that the rock has been dolomitized subsequent to deposition. The percentage of calcium carbonate is sometimes over 99, while that of magnesium carbonate is occasionally as much as 50.

The fauna of the Magnesian Limestone is very restricted (about 140 species) and most peculiarly distributed. The marked palæontological features are the profusion of individuals in the Middle Fossiliferous Limestone (which appears to have formed a shell-bank in the Middle Magnesian Limestone sea), and their sudden disappearance in the Upper Limestone. No Corals, Echinoderms, Polyzoa, Brachiopods, or Cephalopods have ever been found above the top of the Middle Fossiliferous division, only a few fishes, Gasteropods, Lamellibranchs, Entomostraca, and Foraminifera occurring in the Upper beds. The Lower and Middle Fossiliferous Limestones are marked by the presence of *Productus horridus*, Sow. Fish-remains occur at two horizons: namely, the Marl Slate and the Flexible Limestone, and the beds above these deposits.

The Brecciated Beds, which occur at various horizons, chiefly, however, in the two Middle divisions, constitute the most marked tectonic feature of the Magnesian Limestone of the area. They have been produced by thrusting, which brought about a decrease in the

lateral extension of the Permian. Associated with the breccias are other proofs of thrusting: (1) thrust or shear-planes; (2) disturbed and displaced masses of Lower Limestone; (3) intruded breccias; (4) slickensided and grooved, horizontal and vertical surfaces; (5) cleavage; (6) folding, both on a local and on a general scale; (7) buckling, thickening, and squeezing-out of beds; (8) phacoidal and other structures; and (9) fissuring. The main thrust at Marsden appears to have acted from a few degrees south of east to a few degrees north of west; there are, however, distinct evidences of movement from other directions in different parts of the district. Experiments made on the compressive strength of the rocks affected by the thrust at Marsden indicate that the thrusting reached a maximum of about 300 tons per square foot. Observations made by Mr. S. R. Haselhurst, M.Sc., in the Cullercoats area seem to prove that the thrusting occurred later than the post-Permian movement of the Ninety Fathom Dyke—some faulting in the area is, however, later than the thrusting—and it appears evident that the shattering of the strata was produced prior to the Pre-Glacial era of denudation. It may have been connected with the Miocene movements that produced such marked changes in the physiography of Britain.

CORRESPONDENCE.

THE LIMESTONE FRAGMENTS IN THE AGGLOMERATE OF THE "ROCK AND SPINDLE" VOLCANIC VENT, ST. ANDREWS, FIFE.

SIR,—Since the publication of my note under the above-named title (see GEOL. MAG., May, p. 201) I have to record the further observation of a very remarkable fact. During a recent visit to the "Rock and Spindle" my friend Mr. R. M. Craig, M.A., B.Sc., of the Geological Department, St. Andrews University, and myself found that certain large masses of rock which stand almost vertically in the seaward extension of the agglomerate, and which we had long been accustomed to regard as consisting merely of hardened sandstone—they weather curiously like some of the siliceous sandstones along the shore—were in reality portions of a seam of limestone which must have measured at least 12 feet in thickness. These contain very large crinoid stems, isolated cup corals, polyzoa, etc., and look exactly as if they belonged to some of the beds at the base of the Carboniferous Limestones as exposed on the coast at Pittenweem. Certainly they can scarcely have come from the Calciferous Sandstones, and would accordingly appear to afford the strongest confirmation of the above opinion based almost solely on the palæontology of the fragments at the upper part of the beach.

DAVID BALSILLIE.

DREIKANTER.

SIR,—The reviewer to whom Mr. Grabham objects (GEOL. MAG., May, 1911, p. 239) seems in his review (GEOL. MAG., Feb., p. 85) to describe the words 'dreikanter', 'zeugen', etc., as 'technical terms'.

They are certainly not more technical, and I should have thought even less technical, than the phrases 'facetted pebbles' and 'tabular outliers' which he prefers. They don't mean the same thing, it is true; but supposing they did, the objection to them seems to me that they are German and not English. In so far, I agree with your reviewer rather than with Mr. Grabham. One should distinguish very carefully between the using of foreign words out of laziness or because one is ignorant of one's own language, and the use of a correct technical term. A technical term, to be worthy of the name, should be clearly defined, and should be capable of use in all languages with equal convenience. For this reason it is generally preferable to form technical terms out of Greek or Latin words.

The word 'Dreikante' is not a good technical term. It does not mean a wind-worn pebble, but a tripyramidal or triquetral pebble, and the wind-worn pebbles that have this shape are in a minority. In the second place, being German and not English, it presents peculiar difficulties. Mr. Grabham himself writes of 'a dreikanter', when he means a Dreikante (though it is not clear that he would exclude Einkanter, Zweikanter, Vierkanter, u.s.w.), while the last gentleman who wrote on them in your pages persistently spoke of 'Dreikante' when he meant 'Dreikanter'. German is an excellent language—for Germans; but when I am writing for Englishmen, I prefer to write in English, rather than to risk errors in a foreign tongue.

F. A. Bather.

May 2, 1911.

THE LAND-ICE QUESTION.

Sir,—Though I ought to leave Mr. Deeley to reply for himself, is not the difficulty raised by the Rev. O. Fisher in the Magazine for May, p. 238, removed when we regard the so-called ground-moraine of Boulder-clay as consisting originally of intraglacial material, moved forward at various levels within and with the body of the ice? This is the view forced upon one by the examination of Arctic glaciers, as Garwood and Gregory and others have pointed out. Even in India, as T. D. La Touche shows, some glaciers consist largely of stones. A composite mass of this kind may do a large amount of damage to its floor. The conception of the formation of Boulder-clay as an independent entity under ice is probably not commonly held at the present time by glacialists.

Grenville A. J. Cole.

Geological Survey of Ireland, Dublin.
May 10, 1911.

OBITUARY.

ÉDOUARD FRANÇOIS DUPONT.

Born January 31, 1841. Died March 31, 1911.

We regret to record the death at Cannes, at the age of 70, of É. Dupont, the Honorary Director of the Royal Museum of Natural History at Brussels. The results of his early geological studies on the Carboniferous Limestone of Belgium and on the fossil Cephalopods date from 1859, and he subsequently published observations on the Devonian.

On that subject his most important paper was entitled "Terrain dévonien de l'Entre-Sambre-et-Meuse: Les îles coralliennes de Roly et de Philippeville" (Bull. Mus. R. Hist. Nat. Belg., 1882). Dupont is perhaps best known for his long-continued researches on the Belgian caverns, especially those on the borders of the Meuse and of its tributary the Lesse, some account of which was given in the Geological Magazine for 1866, p. 566. To the Quaternary deposits of the valleys, the fossil mammals, and the question of the Antiquity of Man he devoted much attention, and the results of much of this work was embodied in a volume entitled *L'homme pendant les Ages de la Pierre dans les Environs de Dinant-sur-Meuse*, 1871 (2nd ed. 1872). In 1865 Dupont had published an essay on a geological map which he had prepared of the country around Dinant, his birthplace. In later years he was associated with M. Mourlon, now Director of the Geological Survey of Belgium, in the preparation of a general map of the country, and in many of the separate sheets (on a larger scale) issued by the survey. In his *Géologie de la Belgique* (1880) M. Mourlon has given a list of Dupont's publications up to that date. In 1887 he turned his attention to the Congo, and after personal explorations in that territory he published observations on the geology, anthropology, and other natural history subjects, in *Lettres sur le Congo. Récit d'un voyage scientifique entre l'embouchure du fleuve et le confluent du Kassaï*, 1889.

As Director of the Royal Museum Dupont was much interested in the remains of *Iguanodon*, almost complete skeletons of which were obtained from the Wealden of Bernissart, near Mons, and mounted under his superintendence. A reproduction of the *Iguanodon Bernissartensis*, Boulenger, was set up in the Geological Department of the British Museum (Natural History) and figured with descriptive remarks by Dr. H. Woodward in the Geological Magazine for July, 1895, p. 289.

Among the later publications of Dupont was an account of "Bernissart et les Iguanodons" in a Guide to the Collections in the Brussels Museum, 1897.

Dupont was elected a Foreign Correspondent of the Geological Society of London in 1879, and a Foreign Member in 1897.

H. B. W.

ALEXANDER SOMERVAIL.

Born March 4, 1841. Died December 30, 1910.

The close of the year 1910 witnessed the death of Alexander Somervail, a worthy successor in his scientific pursuits to William Pengelly, F.R.S., whose post, as Hon. Secretary of the Torquay Natural History Society, he was chosen to fill when its noted founder, the explorer and historian of Kent's Cavern, retired after forty-five years unremitting work. The traditions, activities, and success of the Society were ably maintained by the succeeding secretary for nearly twenty years, when he, too, aged in its service, reluctantly resigned only a few months before his decease in Torquay on December 30, 1910, in his 70th year.

Alexander Somervail was born in 1841 in the Water of Leith

district of Edinburgh, and lived the larger half of his life within and near that centre of intellectual activity. His self-contained and contemplative temperament was early displayed in his solitary habits, and the interest he took in collecting 'curios' and an earnest regard for the study of nature which increased with growing years. To follow this inclination became his chief relaxation and recreation during the time he could spare from the business occupation which formed his necessary means of livelihood. With the care, attention, and judgment which ensure success he found himself, at length, the proprietor of a prosperous business in Edinburgh.

During these years he had associated himself with the learned Societies of the city, and became a member of the Philosophic Institution, the Naturalists Field Club, and the Geological Society of Edinburgh. He was thus brought into contact with many of the leading men of science in the city, and with such help and stimulus he soon became a keen student and active member. Turning his attention chiefly to geology he devoted all his spare time to traversing and examining the country around Edinburgh so as to gain practical knowledge of the district geologically.

Finding the severe winters of Edinburgh affecting his health he determined to leave his native place for a milder climate. Consequently in 1880 he started a business in Falmouth. There he met Mr. Howard Fox, F.G.S., whom he also inspired with an enthusiasm for geological research, by which a warm friendship was established, resulting in many visits to the strange complex of rocks of the Lizard district, and other geological excursions, even as far afield as the Western Isles of Scotland. Some of the results of these investigations were placed before the Royal Geological Society of Cornwall, for which that body later on elected him an honorary member. For his paper on "The Geology and Scenery of Falmouth and District", read before the Royal Polytechnic Society of Cornwall, he was awarded the bronze medal of that Society.

After two years residence in Falmouth he removed to Torquay, attracted by the Natural History Society and Museum, of which he at once sought membership and was elected in October, 1883, reading his first paper to the Society a month later.

He started a business in Torquay, but soon disposed of it and devoted his whole time and attention to geology and to the work of the Natural History Society. In 1890 he was called upon to take in hand the Honorary Secretaryship of the Society, a work for which he was well fitted. The Society passed through some critical phases during his secretaryship, but the lectures and monthly papers never failed, and his genial presence, courteous interest, and ready help drew many members. His never-flagging enthusiasm for nature study was contagious, and he inspired many to follow Natural History pursuits in the field. He attended the meetings of the British Association, of which, as well as of the Devonshire Association, he was a member, and contributed papers on geology to both.

Having satisfied his desire by a personal visit to the most interesting geological areas in Britain, he sought wider fields for geological observation abroad. Alone and with command of no other than his

native language he rambled the Eifel district, the Auvergne, parts of Norway, and Southern Italy. In the same way he visited Egypt, going up the Nile to the First Cataract, Jerusalem, Damascus, Athens, Constantinople, Vienna, Berlin, and Amsterdam. He also paid a visit to Switzerland and accompanied the British Association in its meeting to South Africa.

His contributions to the literature of geology are contained mostly in the Transactions of the Royal Geological Society of Cornwall and of the Devonshire Association, in the Geological Magazine, and the Journal of the Torquay Natural History Society, the present number of which contains a list of twenty-four of his geological papers. Unfriendly criticism attended the publication of some of his views, but he never alluded to the matter nor appeared to resent the harshness of the treatment.

His interest in geological matters continued unabated. Apparently little concerned by his critics he pursued his favourite study satisfied with the new facts and interest it unfailingly gave him. The value of his services to the Torquay Natural History Society will be long appreciated, and his memory will be kept green by a legacy left by him to its funds, which betokens the interest and pleasure he experienced in the performance of his duties to that institution.

H. J. L.

PROFESSOR M. H. NEVIL STORY MASKELYNE, M.A., Hon. D.Sc. Oxon., F.R.S., F.G.S.

Born 1823. Died May 20, 1911.

With deep regret we have to announce the loss of the well-known mineralogist Professor Story Maskelyne, at his residence, Basset-Down House, Swindon, Wilts, at the age of 87. His grandfather, Nevil Maskelyne, was Astronomer Royal for forty-seven years; his father was a Fellow of the Royal Society and a double-first at Oxford when he was 19. Mr. Maskelyne followed his father, and graduated from Wadham College, Oxford, of which, afterwards, he became an honorary Fellow. He was Professor of Mineralogy in Oxford 1856–95.

But his most distinguished services to Mineralogy are those associated with his appointment of Keeper of Minerals in the British Museum in 1857, a post which he held for twenty-three years, until he entered Parliament in 1880. The collection he found was but a small one, but by timely purchases he was enabled to make it probably the best in the world. He practically created the collection of Meteorites, now one of the finest in existence. His researches in the structure and composition of Meteorites were amongst the most important of his time, and led to the discovery in 1862 of a new mineral in the Busfee Meteorite, which he named 'Oldhamite', and in 1863 he detected enstatite as a meteoric ingredient. Another new mineral named 'Asmanite' was added in 1869. Commencing in 1858 with only Mr. Thomas Davies to assist him, he acquired (1) the eminent services of Dr. Viktor von Lang; (2) W. J. Lewis, F.R.S., now Professor of Mineralogy in Cambridge; (3) Dr. Walter Flight, a very able chemist; and (4) Mr. Lazarus Fletcher, M.A., F.R.S. (afterwards his successor as Keeper of Minerals and now Director of the Natural History Museum).

Mr. Maskelyne was elected a F.R.S. in 1870, and was awarded the 'Wollaston Medal' by the Council of the Geological Society in 1893, in recognition of his great services to Mineralogy. He represented Cricklade in Parliament 1880–5, and North Wilts. 1885–92.—*Morning Post*, May 22, 1911.

MISCELLANEOUS.

Geological Survey of Great Britain.—Dr. John Horne, F.R.S., who joined the staff of the Geological Survey in Scotland in 1867, retires from the public service on June 30. As notified in the Geological Magazine for April, 1901, Dr. Horne was appointed in that year Assistant Director for Scotland, under Dr. Teall as Director. Dr. Horne's service, which has extended over nearly forty-four years, has ever been characterized by enthusiastic and strenuous labour whether in the field or in the office, and by much brilliant research in all parts of Scotland, notably in the North-West Highlands.

We learn (from *Nature*, April 13) that Dr. J. S. Flett has been appointed to succeed Dr. Horne as assistant in Scotland to the Director of the Geological Survey. Dr. Flett is a graduate of Edinburgh University, where he was Baxter Scholar, Falconer Fellow in Geology, and a Heriot Research Fellow. He was for four years lecturer on petrology in the University, and in 1901 joined the Geological Survey. In 1903 he was appointed petrographer to the Survey. After the West Indian eruptions in 1901 he was sent out with Dr. Tempest Anderson by the Royal Society of London to report on the volcanic phenomena. He has published many scientific papers dealing principally with the volcanic and metamorphic rocks of the British Isles, and he has contributed largely to the memoirs of the Geological Survey, not only on Scotland, but also on Cornwall and Devon. For scientific research he was awarded the Neill Medal by the Royal Society of Edinburgh (1902) and the Bigsby Medal by the Geological Society of London (1909).

The First Universal Races Congress is to meet at the University of London, July 26–9, under the presidency of the Right Hon. Lord Weardale, and with the Right Hon. Lord Avebury as one of the Vice-Presidents. The Congress aims to be an assemblage of members of all the races of the world. Professor A. C. Haddon will give a "Demonstration of Racial Types", and he is Director of the Exhibition that will be organized in connexion with the Congress.

The Tenth International Geographical Congress will be held in Rome in the week beginning October 15, under the presidency of the Marquis Raffaele Cappelli. It is interesting to note that the Congress will be divided into the following sections: (1) Mathematical Geography, (2) Physical Geography, (3) Biogeography, (4) Anthropogeography and Ethnography, (5) Economic Geography, (6) Chorography, (7) Historical Geography and History of Geography, (8) Methodology and Didactics.

International Volcanological Institute at Naples.—Although for some time past an observatory has existed on Vesuvius, the means at command have always been insufficient to carry on the systematic